The CHARLES LATHROP PACK FORESTRY FOUNDATION

Reproductive Habits of Douglas-Fir

By

LEO A. ISAAC, Associate Silviculturist

Pacific Northwest Forest and Range Experiment Station

U. S. Department of Agriculture

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FOREWORD

A Field Manual on Growing Douglas-Fir

W. B. Greeley

Most of the books on American forestry have been handed down to us like the Tables of Commandments handed down to Moses. They are brought off the press by the zeal of the writer or his organization, in the hope of reaching a group of more or less interested readers. It is heartening to know that this book on growing Douglas-fir has been put in print because of the demand from foresters and loggers who want it as a working tool, right now.

It is good fortune for the Douglas-fir region that the results of the thorough studies by Leo Isaac and his associates are ready for our use at this particular time. The region is fortunate in having been the center for many years of painstaking research by the United States Forest Service. Such research alone can produce a checked and proven manual on forestry. Timber growing has reached the point where land owners and foresters need a field book on Douglas-fir. And behold! here is one ready and waiting. It is doubtful if any other publication on forestry has appeared at such an opportune time or with such prospect for immediate use. This will not be mainly a library or classroom book. Many copies will be quickly soiled and dog-eared by the hands of men at work in the woods.

Timber growing is becoming part of forest industry in the Pacific Northwest. It is signalized by tree farms now approaching a total of 2,000,000 acres, with 1,000,000 acres more in prospect; by the industry-maintained forest nursery at Nisqually, which is producing planting stock for private forest owners; and by the constant expansion in forms of timber conversion predicated upon a continuous, regional growing stock. The demands of world war have accentuated the transition of forest industry from timber mining to timber cropping. More and more, forest owners become convinced that timber growing pays. More and more are they discovering that the marvelous reproductive capacity of the Douglas-fir forest is the greatest single asset of their industry. In a normal process of evolution and the same initiative which brought their fathers and grandfathers here, West Coast woodsmen are learning to grow timber. Two generations ago, their goal was to cruise and own the most heavily timbered section; one generation ago, to build the finest sawmill. Now the most productive tree farm is coming within the horizon of business enterprise.

One who was associated with starting the first forest experiment stations in the United States and with other early efforts of the Forest Service to prepare for the day of timber growing, may be pardoned for a bit of philosophy about casting bread upon the waters. There have been many examples in our forest regions of zealous, persistent research, research whose results often seemed to fall on deaf ears but which was carried on year after year in a determination to build for the future. Here is a fine example of this type of research which is bearing fruit, which has made important contributions to the going industrial practices of the region. There are many other cases of research that is now guiding forest industry; and there will be many more whose results will come to bear as American forestry gets into its stride.

The timber-using industries too easily forget what they owe to this painstaking, and often discouraging, work of the foresters in the federal service. They are too prone to think it is their foresight and initiative alone that have brought about progressive changes in forest management. As a representative of timber-using industry, I want to pay our full measure of tribute to the research work of the Forest Service and to the other great gains that have been made possible by its leadership and cooperation.

As to this book on growing Douglas-fir, it should be in the hands of every forest owner in the Pacific Northwest. Whether you all realize it or not, the value of your property today is represented but partially by whatever thousands of feet of merchantable stumpage it may cruise. The other part of its value, and in the long run—the greater part, is *what the land will grow.* As a prudent owner, you should know what this value is; how to appraise it; how to conserve it. Put this little book on your working shelf, beside your engineering handbooks and log grading rules and fire prevention code. It is part of the kit of a West Coast forest owner.

Seattle, Washington

Reproductive Habits of Douglas-Fir

By

LEO A. ISAAC[1], *Associate Silviculturist*
Pacific Northwest Forest & Range Experiment Station

AUTHOR'S PREFACE

The highly important Douglas-fir region has already been the subject of numerous publications[2] descriptive of its resources, of its trees, of methods of forest utilization, and of the techniques of forest protection and management. The problem of regenerating these forests by natural means has given foresters and land managers concern because of the great area of highly productive land that has failed to restock following logging. This problem in its many ramifications has been a principal subject of study by the Pacific Northwest Forest Experiment Station since its establishment in 1924, and by other agencies both before and since that date. The author himself has been conducting research in this field since 1924, and the results of certain phases of his studies have already been published. Altogether there has accumulated from this research and from 30 years' experience in technical forest management on the national forests and elsewhere a great amount of data bearing on the whole problem of natural regeneration of Douglas-fir forests. It is the purpose of this circular to digest the results of all past research and experience in this field and to present them for use by foresters in the practical management of their forests for continuous production.

The studies specifically discussed in this circular were conducted at a large number of places widely scattered over the region and representing a wide range of site conditions. These areas extended from Darrington, Washington on the north to Oakridge, Oregon on the south and from the coast eastward up the slopes of the Cascade Range to the upper limit of merchantable timber (Figure 1). These studies did not extend to the hotter and drier sites of southwestern Oregon where Douglas-fir is associated with the pines and with a "mock-chaparral" undergrowth.

Phases of the work, such as germination and survival on different sites,

[1]Special acknowledgment is made to Thornton T. Munger for general supervision while the field work for this study was under way, and for a critical review and revision of this publication.

[2]The reader is referred to the partial bibliography of the subject, presented in the list of "Literature Cited," p. 106, and to the footnote references to manuscripts.

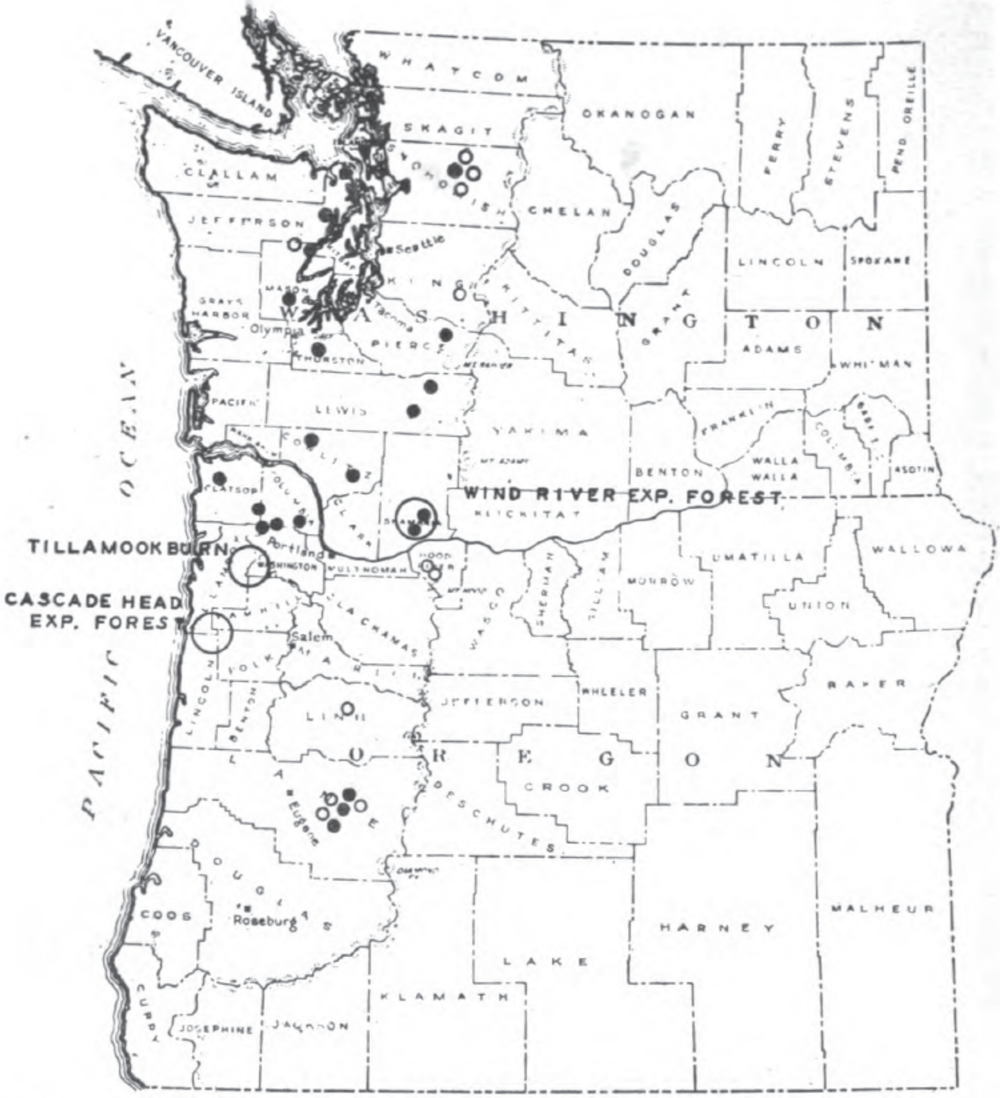

FIGURE 1. Sample plot locations for natural regeneration studies in the Douglas-fir region of Washington and Oregon.

● Germination and survival on different sites.

○ Seed tree survival and seed dissemination studies.

◯ Intensive study areas.

vegetative succession after logging, seed tree survival, seed production and dissemination, were for the most part studied on groups of sample plots that were examined one or more times annually for a period of 10 to 15 years. The locations of these plots are shown in Figure 1. The more detailed and intensive studies, such as environmental factors affecting seedling establishment, soil studies, life of seed after it falls, and shade tolerance of Douglas-fir, were conducted in the vicinity of the Wind River Experimental Forest on the Columbia National Forest near Carson, Washington. Work consisting of merely a single examination, such as reproduction surveys, was done at many other points throughout the region.

INTRODUCTION

The Douglas-fir region of western Washington and Oregon and southern British Columbia is one of the important timber-growing regions of the world. The mild, humid climate and favorable soils are ideal for the growth of conifers, which here produce superlative yields and quality of timber. Except for the agricultural valleys, most of the land is so rugged or mountainous that it will be used always chiefly for forest purposes.

This region, where Douglas-fir (*Pseudotsuga taxifolia* (Lamb.) Brit.) is the principal species, and where it reaches optimum development, extends from the Pacific Ocean to the summit of the Cascade Range and from central-western British Columbia to northern California. On the ocean frontage the spruce-hemlock type prevails; on the upper slopes of the Cascade Range Douglas-fir is replaced by balsam firs (*Abies* spp.), mountain hemlock (*Tsuga mertensiana* (Bong.) Sarg.), and other subalpine species; to the south it is replaced on the coast by redwood (*Sequoia sempervirens* (Lamb.) Endl.), and in the interior by sugar pine (*Pinus lambertiana* Doug.), ponderosa pine (*Pinus ponderosa* Doug.), and their associates; to the north of the Douglas-fir region western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and Sitka spruce (*Picea sitchensis* (Bong.) Carriere) forests prevail. Within these limits Douglas-fir is the dominant tree, occurring either in pure stands over large areas or in mixture with other conifers, forests of the latter category being more common to the north and in the more humid and cooler parts of the region.

The young stands for the most part are even aged and are pure Douglas-fir or contain varying mixtures of western hemlock, western red cedar (*Thuja plicata* D. Don.), Pacific silver fir (*Abies amabilis* (Doug.) Forbes), noble fir (*Abies nobilis* Lind.), grand fir (*Abies grandis* Lind.), western white pine (*Pinus monticola* Doug.), and occasionally a Pacific yew (*Taxus brevifolia* Nuttall). As the stands grow older the proportion of the more shade-tolerant hemlock, cedar, and balsam firs increases (*30*).

Here and there a few hardwoods occur—on moist sites, chiefly red alder (*Alnus rubra* Bong.), bigleaf maple (*Acer macrophyllum* Pursh.), Oregon ash (*Fraxinus oregona* Nuttall), and northern black cottonwood (*Populus trichocarpa hastata* Henry), and on dry sites Oregon white oak (*Quercus garryana* Doug.).

The presence of extensive immature even-aged stands of Douglas-fir on the coming of the white man to the region is evidence that devastating fires had occurred periodically here and there, for in comparison with its associates Douglas-fir is very aggressive in reestablishing itself after burns. Areas which have not been visited by fire in the last 500 years are rare in the region and usually carry forests that have practically advanced to the climax type of tolerant species—hemlock, cedar, and balsam firs.

There were occasional regressions in this march of succession toward the climax type; openings, complete or partial, caused by spot fires, insect injury, or windfall often permitted a new age class of Douglas-fir to

come into a stand in a patchwise fashion. This accounts for the two or more age classes of Douglas-fir that are often found in virgin stands.

Natural forest succession has been greatly upset by cutting and burning activities during the past century. So long as there was only an occasional fire set by lightning or Indians the forest in the region as a whole was able to maintain a certain "equilibrium," though there is evidence that even oft-repeated prehistoric burning in certain localities resulted in deforested brush fields and "prairies." But extensive clear-cut logging followed by slash burning and perhaps successive accidental fires has created a great area of poorly stocked or nonstocked forest land and points sharply to the need for a thorough understanding of the reproductive habits of Douglas-fir and of the technique for obtaining its regeneration following logging.

The first lumbering in the region created no great problem of forest regeneration. It was done with horses or bull teams, on a small scale, usually taking out only the high-value trees and leaving at least a scattered stand of lower-value specimens or an understory of small trees that furnished some shade and an ample supply of seed. With the introduction of steam machinery at the turn of the century, first as ground logging then as high-lead logging, operations extended over larger and larger continuous areas and cut cleaner and cleaner, and the difficulties of natural regeneration became greater and greater. Under the impetus of the laws of both Oregon and Washington[3] slashings were burned broadcast following logging and this practice has had a profound effect upon natural regeneration, as will be shown later.

In recent years steam or gas donkey engine logging—which ordinarily implies very complete falling or destruction over considerable areas—has been replaced, under some conditions, with tractor logging, which permits, and makes advantageous to the operator, the leaving of some trees; thus, partial cutting, or so-called "selective cutting," now has a place in the region.

In theory, this is a return to the partial cutting practiced in bull-team logging that created no great fire or reproduction problems, but in practice it is quite different. The bull-team logging covered small areas at low altitudes and the cut was usually light and patchwise and not very destructive to the reserve stand, while tractor logging is on a far more extensive scale; it sometimes is on a small scale and patchwise, but it often covers vast areas, removes most of the high values, and is very destructive to the reserve stand. While simplifying some aspects of the problem of regeneration, tractor logging creates others.

The term "selective cutting" in definition and in forestry literature presupposes an all-aged forest that will continue to reproduce and maintain the stand under light, frequent cuts of mature trees. But the term has now in common parlance been greatly extended to cover a variety of types of partial removal—purposeful tree selection cutting, "logger's selection" which is the removal of all merchantable trees, and group cut-

[3]For many years the laws of both Oregon and Washington have recognized an unburned slashing to be a menace to life and property, have placed upon owners the responsibility for fires originating therein, and have required the slash to be burned unless exempted by the proper state authority. Under these laws the broadcast burning of slash as a hazard reduction measure has become the usual practice in the Douglas-fir region.

ting in a patchwise fashion which is clear cutting in miniature. To avoid confusion, the term "partial cutting" is applied here to all cutting that is not clear cutting. Care should be taken not to confuse either term with "selective timber management," which may be either.

The forest survey of western Oregon and Washington (*2*) shows that logging practices of the past have been very far from effective in bringing about natural regeneration. In 1934, 21 per cent of the total area cut over prior to 1920, or 660,000 acres, was nonstocked.[4] Of the land cut over between 1920 and 1934 (2,160,000 acres) less than a third is satisfactorily stocked, i.e., medium or well stocked. Results of intensive survey of land in private management logged in the 4-year period 1920-23 shows that 12 per cent is well stocked, 17 per cent medium stocked, 29 per cent poorly stocked, and 42 per cent is nonstocked.

In the resurvey of 18 of the most heavily cut-over counties of the region it was found that only about 22 per cent of the area which was classified as "deforested burn" at the time of the first survey (about 1933) was restocked by about 1940, showing the slow rate at which reproduction filters in on old burns.

Of the 1;238,000 acres in these counties cut over in the decade 1920-29, 630,000 acres (or 49.1 per cent) had restocked by about 1940. Of this cut-over acreage of 10 to 20 years standing that was classed as restocked, only about a half was medium or well stocked, the rest poorly stocked.

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[4]The Forest Survey recognized four degrees of stocking, the term "nonstocked" being applied to areas from 0 to 9 per cent stocked, "poor stocking" from 10 to 39 per cent, "medium stocking" from 40 to 69 per cent, and "good stocking" from 70 to 100 per cent, according to the stocked quadrat method. This method of measuring adequacy of regeneration is based upon the proportion of 13.2-foot squares (1/250 of an acre) comprising the area under consideration that contain at least one established seedling. Stocking in existing stands approaching maturity indicated that the 13.2-foot square was a good average size for the Douglas-fir type when used in stands up to 25 or 30 years old. If all such squares on an acre had at least one established seedling, the acre would have not only 250 perfectly distributed seedlings but in addition would have many more because most of the squares are sure to have several seedlings each. Although only stocked squares were used to determine degree of restocking in published Survey data, they did make checks on the additional number of seedlings present on stocked squares.

Counts of seedlings on thousands of quadrats on lands of various degrees of stocking (but in no case counting more than 11 seedlings on any one quadrat and requiring three 1-year seedlings to be equivalent to one established seedling) showed that on the average each stocked quadrat carried 5.3 seedlings. Thus, an acre which is classified as 50 per cent stocked, i.e., having at least one established seedling on each of its 125 stocked quadrats, has, when using this average figure, a probability of having 662 seedlings (125 x 5.3) even if none over 11 are counted on any quadrat.

However, the heavier the stocking the greater the probable number of seedlings on each stocked quadrat; and conversely in poor stocking the probable number will be less than the average 5.3.

To determine what the probable number of seedlings was for each degree of stocking the *total* number of seedlings was counted on a large number of representative quadrats having one or more established seedlings on each and the results are shown in the table below. The range in average total number of established seedlings per quadrat for each grade of stocking is shown in column 4 and the probable range in number of seedlings per acre is given in column 5.

Grade of stocking	Percentage of squares with one or more established seedlings	Range in average number of stocked quadrats per acre	Range in average number of seedlings per stocked quadrat	Probable minimum and maximum number of seedlings per acre
Nonstocked	0 to 9	0 to 24	1.0- 1.2	0-29
Poor stocking	10 to 39	25 to 99	1.2- 3.2	30-319
Medium stocking	40 to 69	100 to 174	3.2- 8.6	320-1459
Good stocking	70 to 100	175 to 250	8.6-20.4	1460+

Thus an area with "medium stocking" would have from 40 to 69 per cent of the 13.2-foot squares stocked or 100 to 174 of the 250 quadrats per acre stocked; these stocked squares would have an average of 3.2 to 8.6 seedlings each or a probable range in total number of seedlings from 320 to 1,459.

National forest Douglas-fir cut-over land records show that out of 50,000 acres examined 56 per cent were classed as satisfactorily stocked,[5] 38 per cent poorly stocked, and the remaining 6 per cent nonstocked and planted. From 5 to 25 years had elapsed since cutting on these areas.

These comprehensive statistics show very convincingly that the regeneration of Douglas-fir lands following past conventional logging practices is a problem that calls for solution through better understanding of the basic factors favorable and unfavorable to regeneration.

Historical Review

Technical observations on the reproductive habits of Douglas-fir began over 40 years ago with a report by Allen[6] and studies have continued and been augmented ever since; throughout there has been an effort to explain the silvical requirements of the tree and to recommend methods of logging which would promote regeneration and yet be consistent with the exigencies of the type of logging then employed.

Allen,[7] in 1899, wrote: "The old stand must be removed before reproduction is possible." Frothingham (*7*), 1908, stated: "As a general rule, subject to local modification, Douglas fir is best managed in western Washington and Oregon by clean cutting and surface burning." In 1911 Munger (*27*) wrote: "Douglas fir seed germinates in almost any situation that the seed chances to fall, provided there is sufficient moisture, but it is only the seedlings whose roots quickly come in contact with the mineral soil and which receive direct light that survive."

Beginning with the earliest timber sales on the national forests, about 1905, the Forest Service in most instances followed the practice of leaving two Douglas-fir seed trees per acre, usually conky trees or those of low commercial value yet suitable as a source of seed. Broadcast slash burning was followed as elsewhere in the region. The loss of seed trees was heavy and sometimes the restocking was satisfactory and somtimes not; as years passed more trees were left or other sources of seed provided for restocking. On private lands, in practically every logging operation during this period no seed trees were consciously left, yet in places a sprinkling of non-merchantable trees of seed-bearing size survived the logging. Regeneration followed in some places even when there were no seed-bearing trees nearby; in other places there was no reproduction. The causes for these failures and successes were an enigma which stimulated further study.

In 1912 Hofmann commenced studies, chiefly in western Washington, which culminated in the publication of his results in 1917 (*12*) and 1924 (*13*). He gathered a large amount of data on burns and cut-over lands which seemed to show that much reproduction started several years after the forest was cut and where there was no nearby visible source of seed. These observations he interpreted to mean that the seed of the cut, or fire-killed, forest was stored in the duff for some time after it was borne,

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[5]"Satisfactory stocking" in this instance using the "stocked-quadrat method," means that 50 per cent or more of the 4 mil-acre quadrats had one or more established seedlings and this implies at least 125 established, well distributed seedlings on every acre with a probability of there being 650 or more seedlings to the acre.

[6]Allen, E. T. Red fir in the Northwest. 94 pp. 1899. (Mimeo.)

[7]See footnote 6.

retained its viability, and then germinated up to 6 or 8 years thereafter. This gave rise to the so-called "seed storage in the duff" theory and prompted the comfortable feeling that regardless of the presence of seed trees a new forest would spring from seed cast by the cut forest. This encouraged some timbermen to have a false security as to the reforestation prospects of their cut-over lands regardless of the continuance of a seed supply. However, to be on the safe side the Forest Service in administering timber-cutting operations on the national forests did not depart from its policy of leaving at least 2 seed trees per acre.

Subsequent study, as this circular shows, has proven that contrary to the "seed storage in the duff" theory Douglas-fir seed retains its viability in appreciable quantity for only a year after it is borne.

In 1924 the series of studies, the results of which are summarized in this circular, was commenced and soon began to yield tentative conclusions, from which recommendations as to forest practices were made. These have materially affected the methods of silviculture employed on the national forests and by the increasing number of private operators who are seeking to have their lands reforest naturally after logging.

In 1927 Munger (*28*) recommended as a minimum requirement in Douglas-fir logging that "to supplement the stored seed that may survive slash burning and to give more security against complete and permanent devastation by accidental reburns, some seed supply should be provided . . . either in the form of single seed trees scattered over the area or in the form of groups or bodies of uncut timber at not too great a distance."

The forest practice rules adopted in 1934 by the West Coast Lumbermen's Association in connection with Article X of the NIRA Lumber Code (*36*) took cognizance of recent findings regarding seed disposal and seedling establishment and anticipated in some measure the final recommendations of these studies.

On the national forests in recent years where clear cutting is employed, the trend has been toward keeping small the areas of continuous clean logging and relying for regeneration chiefly on seeding from the side or from strips or blocks of seed trees, leaving single seed trees only where there are culls that would not ordinarily be cut. During this same period the earliest attempts at partial cutting were being made in the region.

Kirkland and Brandstrom (*22*) in 1936 advocated a system of selective timber management in the Douglas-fir region which embodied several successive cuts but which mentioned group selection or clear cutting in the final stages of a cutting cycle where Douglas-fir regeneration is desired. They further suggest planting in small clear-cut spots if Douglas-fir natural regeneration is not obtained. This assumes that there is not already an established understory forest of hemlock and balsam firs before a final cut is made, or assumes that there will be a market for this understory if such stand is present.

Godwin (*8a*) in 1938 made a study of a Douglas-fir cut-over area with a sandy loam soil on the east coast of Vancouver Island. Some of his significant findings were: "Of 19,981 acres logged in the past 17 years, 5.4 per cent are satisfactorily restocking;" "Reproduction is unsuccessful in areas of unburned slash when no fire has occurred before logging;"

and "The occurrence of moss (*Polytrichum juniperinum*) on burned lands is a factor limiting the establishment of reproduction."

Where partial cutting, or "selective logging," is practiced, an entirely new set of problems is encountered. In the case of clear cutting it is a problem to provide an adequate seed supply, to attain satisfactory dissemination, and to provide a seed bed that is hospitable for the survival of the young seedlings—neither too hot nor dry nor exposed. With partial cutting—in addition to distinctive economic and fire prevention problems—there is ordinarily sure to be plenty of well distributed seed, but it may be of species other than Douglas-fir and the ground may be too well shaded for the survival of Douglas-fir reproduction and a change in composition of the forest may ensue. Since hemlock and its tolerant associates, which reproduce readily in the shade, are not the most satisfactory species for the main crop where they do not produce good timber trees, as in over two-thirds of the region, the failure to get Douglas-fir regeneration on such lands would be unfortunate. Where partial cutting is desirable or contemplated in the conversion of virgin stands to managed forests the foregoing fact presents a real problem yet to be solved.

THE SEED SUPPLY

Periodicity of Cone Production

Douglas-fir, in common with its principal associates, western hemlock, western red cedar, and Sitka spruce, is a prolific producer of cones and seed. Some seed is produced by Douglas-fir forests annually except for about 1 year in any 4- or 5-year period. General observations made over the region at large from 1909 to 1941 indicate an abundant crop of cones in 7 of the years, a medium crop in 6, a light crop in 13, and a cone crop failure in 7 of the years. This record is shown in Table 1. It is not based wholly on observations at any one point, but is the summation of reports from the region at large made by different people. Some years the crop is quite uniform throughout the region; in others it is not. The cone crop is usually heavier on poor sites, such as gravel soils and wind-swept ridges, than on good sites.

Some young trees, particularly those growing in the open, begin cone production when 10 to 15 years old, the cones containing viable seed. Production increases gradually until the tree reaches maturity, then declines. An overmature stand, 675 years old, on the Olympic Peninsula now being logged is still producing viable seed. The largest known Douglas-fir, 15.5 feet in diameter breast high, is still producing cones. (Plate 1.)

TABLE 1.—General Rating of Douglas-Fir Cone Crops in Western Washington and Oregon from 1909 to 1941

Year	Rating	Year	Rating	Year	Rating
1909	Medium	1920	Light	1931	Light
1910	Failure	1921	Light	1932	Medium
1911	Abundant	1922	Failure	1933	Medium
1912	Light	1923	Abundant	1934	Abundant
1913	Failure	1924	Failure	1935	Light
1914	Abundant	1925	Light	1936	Abundant
1915	Light	1926	Light	1937	Light
1916	Failure	1927	Light	1938	Medium
1917	Light	1928	Light	1939	Medium
1918	Abundant	1929	Light	1940	Failure
1919	Failure	1930	Medium	1941	Abundant

Even in years of heavy cone crops not all the trees produce. When there are cones on trees in virgin stands, there are usually cones on open-grown trees, but the reverse is not always true. Even open-grown trees fail to flower some years, and individual forest-grown trees probably produce seed less than half the time, i.e., some trees may rest even during good seed years. A record of the variation in seed-producing habits of individual trees is furnished by the record of a Douglas-fir seed-tree plot during 1927, when there was a good seed crop. In this instance 24 per cent of the trees bore a heavy crop, 41 per cent medium, 23 per cent light, and 12 per cent none. A variation always exists regardless of crop abundance.

There are years when Douglas-fir fails over extensive areas to produce

PLATE 1.—Largest and probably the oldest living Douglas-fir tree—15.5 feet in diameter at breast height, 13.5 feet in diameter above the butt swell, and 208 feet high to a broken top. The tree, growing in Clatsop County, Oregon, is in healthy condition and is still bearing cones. It is the last remaining veteran from a former Douglas-fir forest that has now advanced to a climax forest of hemlock and spruce.

flowers in the early spring ordinarily following a year of heavy cone production, yet in other years it flowers but fails to produce viable seed. This latter condition probably must be attributed to unfavorable weather during pollination. It has been observed that some years the heaviest crop is on old-growth trees; in other years on young trees; while at other times young and old trees, forest and open-grown, produce alike.

In some years the species of trees associated with Douglas-fir have a good cone crop simultaneously with that of Douglas-fir; in other years a cone crop failure is general with all species; but often there is no direct correlation between the cone production of different species, indicating that each has a different periodicity and reaction to weather in its seed-producing habit. Table 2 reflects a comparison of seed production of several species in one locality through a term of years.

Quantity of Seed Produced

In general, trees with large crowns bear more seed than trees of the same age and diameter with small crowns. No difference has been noted between the seed production of sound trees and "conky" trees, i.e., those affected with ring scale fungus, *Fomes pini,* and other fungus diseases.

Open-grown trees with large crowns have yielded as high as 18 bushels of cones in one picking, but the average forest-grown tree, which has a

TABLE 2.—NUMBER OF SEEDS BY SPECIES FALLING PER ACRE ON THREE AREAS IN THE WIND RIVER EXPERIMENTAL FOREST, WASHINGTON—1932 TO 1942

Areas	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	Average per acre per year	
100-year-old forest almost pure Douglas-fir	(Values in thousands of seeds per acre)										No. seeds	Pounds
Douglas-fir						5	123	29	0	12	34	.845
Western hemlock						6	18	8	1	9	8	.028
Western red cedar						*	1	1	0	1	1	.002
Balsam firs						0	22	0	0	4	5	.347
Total						11	164	38	1	26	48	1.222
Overmature mixed virgin forest												
Douglas-fir	166	8	123	22	308	28	446	19	0	212	133	3.33
Western hemlock	4,039	204	3,301	20	1,055	456	5,578	131	0	2,409	1,719	5.73
Western red cedar	5	1	2	*	75	3	253	6	0	369	71	.20
Balsam firs	9	0	3	0	13	0	17	0	0	4	5	.31
Total	4,219	213	3,429	42	1,451	487	6,294	156	0	2,994	1,928	9.57
Cut-over area—200 to 1,000 feet from virgin forest												
Douglas-fir	93	10	100	6	67	8	115	6	*	122	53	1.32
Western hemlock	72	32	64	6	32	15	76	6	0	185	49	.16
Western red cedar	0	0	0	0	*	*	*	0	0	2	*	.0005
Balsam firs	4	0	*	0	1	0	0	*	0	3	1	.05
Total	169	42	164	12	100	23	191	12	*	312	103	1.5305

NOTE: Asterisk indicates less than 500 seeds per acre; amounts over 500 were considered 1,000 seeds. Pounds per acre were based on the following number of seeds per pound—Douglas-fir 40,000; western hemlock 300,000; western red cedar 350,000; and balsam firs 15,000.

narrow crown, yields about 1½ bushels during a good seed year. This quantity of cones produces about 1 pound of cleaned seed, or from 35,000 to 45,000 seeds. This finding of the present author closely confirms the observations of Hofmann (*13*) who said: "... the average mature Douglas-fir tree produces about 40,000 seeds per crop." Since many trees in forest stands produce little or no seed even on "seed years," the average production per tree is considerably less than 1 pound.

A record of seed production of some random-selected young trees near Rujada, Oregon,[8] showed that beginning when they were 12 to 16 years old, 61 per cent of them produced cones in the succeeding 7 years with an average of 83 cones per tree, whose seed tested from 0 to 85 per cent fertile on cutting. Hofmann (*13*) stated: "It was found that the average 15-year-old tree produced 4,000 seeds (annually), the average 100- to 200-year-old tree produced 40,000 seeds, and the average 600-year-old tree produced 7,000 seeds."

A measure of seed fall was obtained for the period 1932-41 by placing seed traps in 3 areas on the Wind River Experimental Forest. The results are shown in Table 2. Area number 1 carried a 100-year-old stand, almost wholly Douglas-fir and balsam fir except for a few small understory hemlocks and cedars; area number 2 was a virgin stand of decadent large Douglas-fir, and more numerous but smaller hemlocks with some cedars and balsam firs; area number 3 was cut-over land adjoining area 2, and the traps were placed from 200 to 1,000 feet from the timber's edge.

It is notable that the seed fall of Douglas-fir, under the 100-year-old stand is only 26 per cent of that under the virgin stand. The cut-over land, 200 to 1,000 feet from the timber's edge, is receiving 40 per cent as much Douglas-fir seed as falls directly under the virgin forest, but a much smaller percentage of the other species.

In this locality, as Table 2 shows, there was practically a complete absence of seed production in 1940, but an excellent crop from all species in 1938. In that year over 6 million seeds fell per acre beneath the virgin forest, of which nearly half a million were Douglas-fir. Here Douglas-fir produced at least a fairly good amount of seed almost every other year, as did hemlock, and a little seed on the alternate years except for the failure of 1940.

Season of Seed Fall

Douglas-fir cones start to open and shed their seeds about September 1. Since the cones open in dry weather after maturing, and partially close in moist weather, the period of dissemination may vary greatly according to the occurrence of dry or wet weather. In a normal season approximately two-thirds of the seed falls before the end of October, and the remaining third reaches the ground during the late fall, winter, and spring. Sound seeds have been found in cones and seed traps as late as June 1.

The seeding habits of the associates of Douglas-fir are similar; they, too, shed most of their seeds in the early fall, but hold some for later dissemination during dry weather periods. Even the large seeds of the balsam firs, whose cones fall to pieces when mature, cling to foliage and pitch and may not reach the ground for weeks or months after the cones have

[8]Manuscript records in Regional Forester's office, Portland, Oregon.

disintegrated. Such seeds, along with those of Douglas-fir, hemlock, and cedar have been caught in seed traps and found on fresh snow in February and March.

Pickford (*33*) found in southwestern British Columbia that less than half of the Douglas-fir seed had fallen by the end of October, and that about a third fell after the first of March, which indicates a somewhat more protracted period of dissemination than in Oregon and Washington. He reported that seeds of both Douglas-fir and hemlock continued to fall until June, which coincides with observations of the author, but that western red cedar seeds reached the ground in decreasing amounts throughout the 12-month period.

Method and Distance of Seed Dissemination

A Douglas-fir seed, like that of most of the other conifers and many broadleaf trees, has a wing which whirls the seed as it drops from the cone, retarding its fall so that air currents have time to carry it away from the base of the parent tree. (Plate 2.) Whirling seed falls at the rate of 175 to 250 feet per minute so that it would take only a gentle wind to carry the seed several hundred feet laterally in the minute it was falling from the

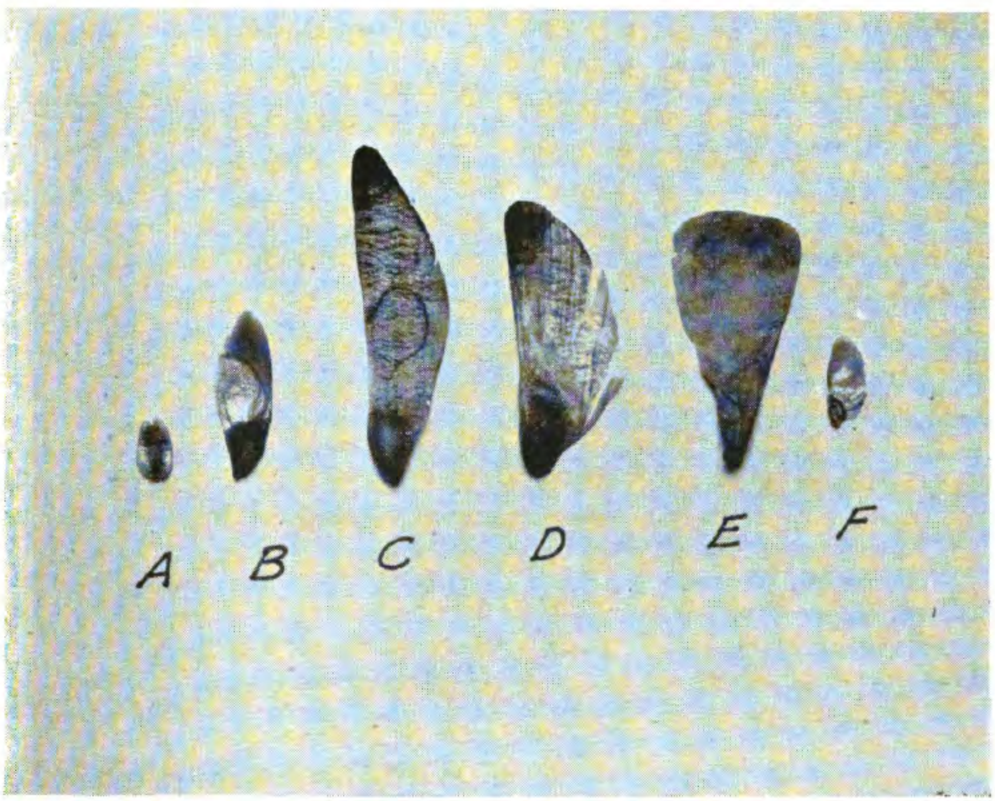

PLATE 2.—Seeds of important Northwest species with wings attached. A—western red cedar, B—Douglas-fir, C—western white pine, D—ponderosa pine, E—noble fir, and F—western hemlock. The wing causes the seed to whirl as it falls from the tree. This slows up the rate of seed fall and allows it to be carried great distances by the wind.

crown of a tall tree. Moreover, there are sometimes rising air currents, caused by superheating of atmosphere over warm slopes, which actually carry the seed upward and suspend it so long that it might be carried laterally long distances before coming to earth. Vertical air currents, called "bumps" by fliers, exceeding 10 miles per hour have been recorded (*9*). The writer has field evidence from seed caught in traps and from the occurrence of seedlings on plots that occasionally seed is carried several miles by such rising air currents in conjunction with horizontal wind movement. Reynolds[9] in Mississippi found fields seeded to shortleaf and loblolly pine at a distance of 1.9 to 2.5 miles from the nearest source of seed. Vertical air currents set up by great fires often carry seeds long distances. During the Dole fire in southwestern Washington in October 1929, seeds with scorched wings borne on a pall of smoke were found in seed traps on the Wind River Experimental Forest more than 10 miles to the leeward of the nearest edge of the fire. Conversely, falling air currents over cool slopes might cause seed to fall rapidly and drop to the earth very close to the parent tree.

Horizontal and vertical air movement is so variable that it is not possible to state positively the normal or average distances of dissemination. Much depends on the topography, the location of the seed supply, the humidity, and the winds at the time of cone opening. The pattern of dissemination might be different even in successive years on the same area. Undoubtedly a majority of the seed crop falls within tree height of the parent tree or the edge of an uncut patch of timber. Yet cones open most freely on hot dry days, and if these were coincident with brisk east winds, which are not uncommon at cone-opening time, a good proportion of the seeds might be carried considerable to leeward of the base of the seed trees.

Some data are available both from catches of seed in traps at stated intervals from the seed source and from experimental releasing of seed from kites on level snow fields (*15*).

In a measure of the natural seed fall throughout a season at 100-foot intervals from virgin timber, 39 per cent of the Douglas-fir seed caught in traps fell at the 100-foot point from the timber's edge (excluding that which fell under the timber), 44 per cent fell between the 200- to 500-foot points, leaving only 17 per cent that fell 600 feet or more from its source. This is shown graphically in Figure 2. Some hollow seed was caught in the traps half a mile from the seed source, but the fall was very light beyond the quarter-mile point.

The pattern of seed flight when Douglas-fir seed was released from kites at tree heights over level snow fields is also shown in Figure 2. The maximum density of fall with a surface wind velocity of 7 miles per hour was 1,000 feet from the point of release and the maximum distance of flight was 1,800 feet. In a 23-mile-per-hour wind the seed fell in maximum density at 1,600 feet from the point of release and some was carried as far as 3,500 feet. Of the associates of Douglas-fir, western hemlock, Sitka spruce, and western white pine made a slightly longer flight in these tests, while western red cedar, ponderosa pine, and the balsam firs travelled slightly shorter distances than did Douglas-fir.

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[9]Reynolds, R. R. Natural seeding of shortleaf and loblolly pine over long distances. U. S. Forest Service, Service Bulletin 17 (17): 3. August 14, 1933 (mimeographed).

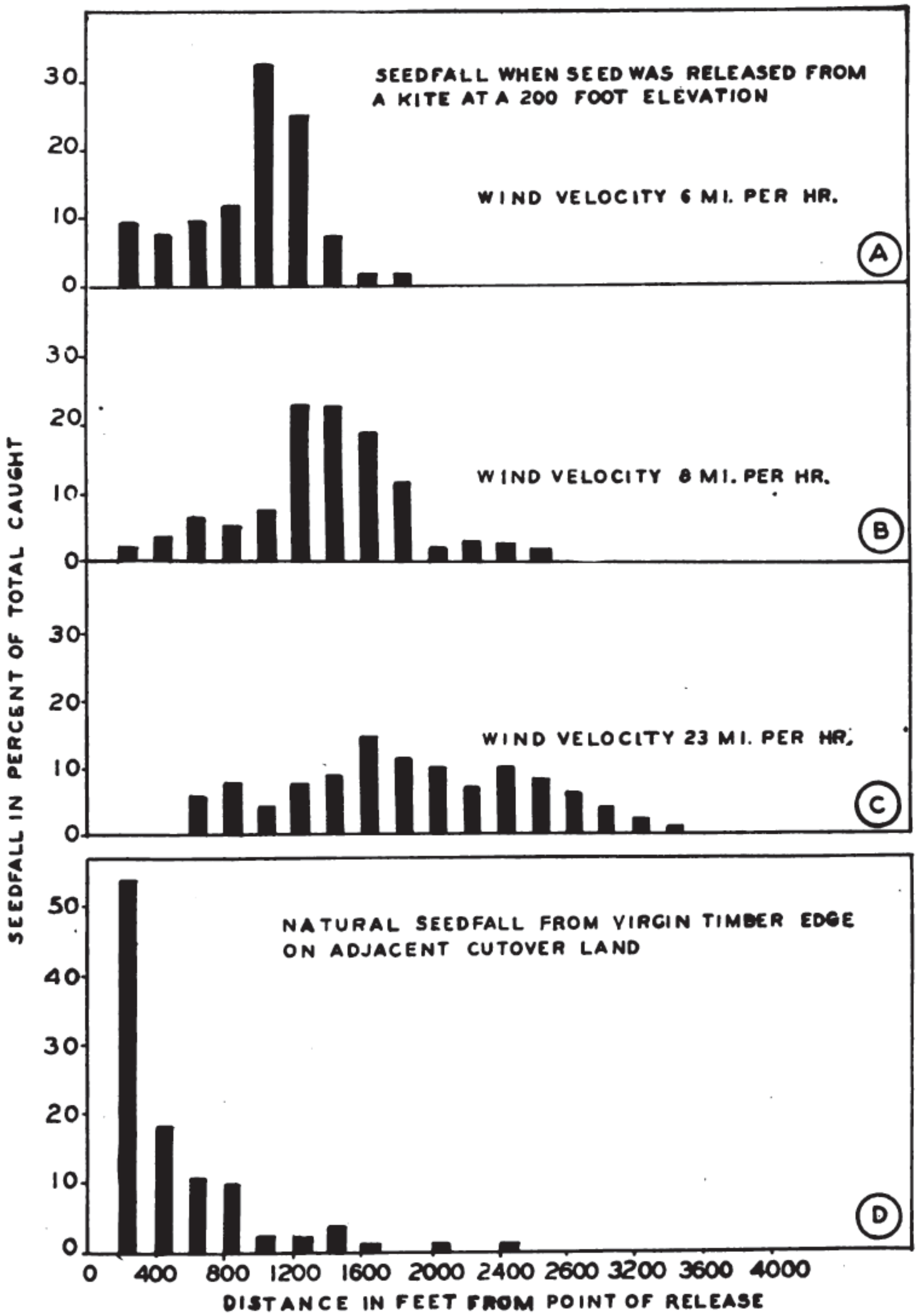

FIGURE 2. Douglas-fir seed fall at various distances from point of release. Diagrams A, B, and C illustrate pattern of seed fall when it was released from a kite at tree heights over a level snow field. Diagram D illustrates pattern of natural seed fall at 200-foot intervals out from a timber edge during a season of light seed crop, as indicated by seed caught in traps.

In general, the occurrence of reproduction on logged-off land substantiates the pattern of seed flight shown by the seed-trap and kite tests. Case histories showing distribution of regeneration on cut-over lands adjacent to green timber that constitute field examples of effective seeding distances on different exposures are shown in a later section. An adequate amount of regeneration often occurs as far as a quarter of a mile from the timber's edge within a 10-year period. Though there are many factors to consider in obtaining restocking of logged-off land besides the distance of abundant seed flight, it is now generally recognized that for normal topographic and climatic conditions seeds of Douglas-fir and its associates will be disseminated in quantity a quarter of a mile from a given abundant seed source. But it must be definitely borne in mind that if conditions for seedling survival are less favorable than average, adequate restocking will take place for a proportionally shorter distance, and, conversely, if survival conditions are better than average adequate restocking may take place beyond the quarter mile point. Instances of seeding at greater distances from the seed source will show a decrease in density of fall proportional to the increase in distance, and must be considered as exceptions due to phenomenal wind conditions, such as cited above, and to unusually large sources of seed.

The quantity of seed falling at certain distances from its source is probably not proportional to the volume of seed produced. In a dense forest much of the seed borne by the interior trees is screened by neighboring trees from traveling any great distance; it is, therefore, chiefly the seed from the marginal trees that escapes this screening effect and flies widely over open areas. Single seed trees can accordingly be expected to show, proportional to their volume of seed produced, a wider pattern of dissemination than a solid wall of virgin timber. Likewise, a narrow strip or patch of uncut timber may scatter its seeds farther, in proportion to its volume of seed, than a large body of timber.

Though wind is the major agent in transporting seed, mice, chipmunks, and squirrels play a small secondary role in gathering up seed, carrying some of it away from the parent tree and burying it so that the seeds not eaten have a better chance to germinate than those that lie as they fall. There is no evidence to show that Douglas-fir seed passes through the alimentary canal of birds without losing viability—a prominent method of seed dissemination with some trees such as juniper.

The foregoing indicates clearly that to achieve reforestation seed trees need not be located on every acre, or even every 10 acres, provided there is a sufficient source of seed within seeding range (maximum of a quarter of a mile under favorable conditions) of every part of an average tract to attain reforestation, after due allowance is made for germination ratio, first-year mortality, and failure of final seedling establishment, as discussed later.

Seed Destruction by Various Agencies

Insects

Of the several insects that destroy Douglas-fir seed, the two most important are the fir cone moth (*Barbara* spp.) and the seed chalcid (*Magastigmus spermotrophus*). Their work is described by Keen (*20*). The fir cone moth, small, gray, and half an inch long, lays its eggs on budding

cones; these hatch into yellowish-white caterpillars that mine through scales and seeds to the heart of the cone where the pupae remain over winter. The seed chalcid is a small wasp that drills through young green cones and lays its eggs within immature seeds. The small, white, legless larvae feed on the tissue within the seed, and there is no outward evidence of its presence until the mature small wasp emerges in the spring through a small round hole in the seed coat. These two insects are always present in the endemic stage, but may and have from time to time increased to a point where they have destroyed up to 75 per cent of the season's crop. No effective field control has been worked out.

Rodents and Birds

Seed consumption by rodents is without doubt a most important factor in reducing the seed supply available for germination. Douglas's squirrel (*Scuirus douglasii douglasii*), the chipmunk (*Eutanias townsendii*), and the white-footed mouse (*Peromyscus* spp.) are the most common seed-foragers of the region. The former begin their activities in the late summer, cutting the green cones from the trees and storing some for later use. The white-footed mouse works incessantly, picking up freshly fallen seeds, but, because he is a nocturnal feeder, is seldom seen. He is known to be as great a consumer of tree seeds as the squirrels, or chipmunks, if not greater (*23*). The white-footed mouse population is usually not heavy in the virgin forest, but builds up rapidly after logging. Their numbers may be reduced, but they are not eliminated by slash burning according to Moore (*25*). On a 1-acre sample plot in freshly burned slash near Cascade Head Experimental Forest, Otis, Oregon, 34 mice were live-trapped and earmarked, to prevent recounting, between November 1937 and April 1938, and in addition 6 shrews (*Sorex* spp.) were taken. On an unburned area less than 1,000 feet distant, 14 mice and 76 shrews were taken on an acre plot. During the same period of time, 35 mice were trapped on an acre plot in a 5-year-old slash-burned area near Ryderwood, Washington. It is not difficult to understand how mice in such numbers, working from early fall to germination time in the spring, could go a long way toward consuming a season's seed crop.

Shrews, though classed as insectivora, have recently been reported as feeding on Douglas-fir seeds (*25*), and they may be a considerable factor in seed destruction in the coast region where they abound.

Birds, particularly winter residents like the juncos and sparrows, are heavy consumers of tree seeds and no doubt account for the disappearance of a considerable share of the crop.

The rodents and the birds together practically clean up the seed in years of light or medium crops; apparently a surplus is left for germination only when there is a heavy crop. The notable fluctuations in mouse population may be in part due to fluctuations in the food supply of tree seeds, and conversely low points in rodent population may have a favorable relation to seed survival and the establishment of tree reproduction.

Rodents have, on the other hand, some beneficial effect on seed supply, by reason of their habit of burying a mouthful of seed in the soil and failing to retrieve it. These caches being where the seed has a good chance to germinate may result in seedlings where the same amount of seed lying

on the surface where it fell would fail to germinate. This is not considered an important factor in Douglas-fir regeneration as it is on some soils with ponderosa pine seed.

Slash and Crown Fires

Slash burning is very destructive of seed, but some of that on the ground may survive a light burning-over of the surface—just what percentage is difficult to determine. Morris (*26*) found in oven tests that dry (7 per cent moisture content) Douglas-fir seed would withstand temperatures up to 150° F. without material loss of viability, but moderately moist seed (30 per cent moisture content) that showed 60 per cent germination after heating to 122°, lost its viability completely when heated to 140°. Hofmann (*13*) found that buried seed survived when slash fires raised soil temperatures to 120°. However, slash fire temperatures are high and often burn deep into the surface soil layer. In the upper 1-inch layer of mixed mineral soil and duff on a cut-over area, the author recorded a temperature of 608° in a hot slash fire. An extremely hot, clean burning is certain to consume all seed, while a light, patchy one would destroy proportionally less. Fall slash fires that occur when duff is dry as a rule burn deeper and hotter than spring fires that occur when the lower layers of duff and soil are likely to be moist. But whether spring or fall burned, unless slash is extremely light or seed happens to be protected by a layer of mineral soil or moist duff, seed cannot be expected to survive and sample plot records indicate that very little does survive.

When a crown fire sweeps through a forest in late summer, the seed in unopened green cones is destroyed when fires are extremely hot, but when not extremely hot such seed often escapes destruction and is shed later, even though the parent trees are killed. This occurs because green cones are good insulators and are not highly inflammable. Hofmann (*13*) says, "seed in cones on trees will live through a forest fire"; he subjected cones to temperatures up to 1100° F. for periods of 1 to 15 minutes without destroying the viability of seed.

Well developed cones clung to fire-killed trees following the great Tillamook burn of August 1933 in places where the crown fire had not been extremely hot.[10] Many of these cones were cut by the author and were found to contain well filled seeds in good condition; later these cones opened and shed their seed on the freshly burned surface. The same phenomenon has been observed after forest fires elsewhere in the region and on seed trees on cut-over areas killed by the slash fire; it can only occur during years when there is a seed crop and with late summer or early fall crown fires or slash fires.

Seed Survival on the Ground

Of the seed which falls to the ground and is not eaten by rodents and birds, some falls on rocks, logs, and stumps where successful germination is impossible, and some falls on bare mineral soil or more often on moss, litter, or duff-covered surfaces. The length of time that this seed remains viable after it falls is of vital importance in estimating how much seed is

[10] Isaac, Leo A. and Meagher, G. S. Natural reproduction on the Tillamook burn two years after the fire. Pacific Northwest Forest and Range Experiment Station. 19 pp., maps. March 5, 1936. (Mimeo.)

present in the soil at the time of cutting or slash burning, and what regeneration may be expected from it.

A number of years ago (*12*) (*13*) the theory was advanced that some Douglas-fir seed remained viable several years after falling to the ground, and that, therefore, seed might lie some time on the floor of the virgin forest, where conditions were not conducive to germination, and then germinate when logging let in the light and warmth and stirred up the ground. Thus, the reproduction on logged-off lands and burns apparently beyond seeding range of existing live trees was ascribed to seed stored in the duff of the virgin forest perhaps from several seed crops. Western white pine was known to exhibit "delayed germination" and the same habit was ascribed (wrongly it now appears) to Douglas-fir. Hofmann (*13*) tested this theory in 1916 by artificially storing seed in the forest. He obtained fair germination the first year, very little the second, and none thereafter; he attributed the failure of germination after the second year to rodent disturbance of the seed containers buried in the duff.

To test the behavior of Douglas-fir seed after it falls to the floor of the forest, fresh seed was collected and placed by the author (*16*) in soil-filled, rodent-proof cages and buried in three positions—just under the surface, 1 inch below the surface, and 2 inches below. Four sets of 700 sound seeds each were placed in the duff of the virgin forest and four others in an open cut-over area. One set was taken up each spring for four successive years. They showed in each case normal germination the first year, a negligible amount the second, and none thereafter. Moreover, the seed left in storage showed vigorous germination in place the first season after it was harvested, but none thereafter, both in the lots stored in the timber and in the open. (Plate 3.)

Examination of the seed as it was taken up showed after the first year that it had either been cracked open in the process of abortive germination or had decayed. The study was replicated twice thereafter in a period of 9 years, except that 1,000 sound seeds were used instead of 700; in all three instances similar results were obtained. To still further test the "seed storage theory" as applied to the associates of Douglas-fir, as well as to Douglas-fir again, another experiment was installed in 1936 using the same technique and the following species: Douglas-fir, western hemlock, western red cedar, ponderosa pine, western white pine, Sitka spruce, noble fir, and Port Orford white cedar. Normal germination with all species was obtained the first season and none thereafter, except for 1 per cent germination of western white pine in the second year and .5 per cent germination of Port Orford white cedar in the third and fourth years. The second-year germination of white pine with its heavy seed coat and reputation for "holding over" in nursery beds was expected, but the third- and fourth-year gernation of Port Orford white cedar, small though the amount was, came as a complete surprise.

A similar test by Haig et al (*11*) at the Northern Rocky Mountain Forest and Range Experiment Station, with western white pine, Douglas-fir, western hemlock, grand fir, and western larch, showed 25 per cent of the white pine viable after 2 winters' storage, less than 1 per cent after 3 and 4 years' storage, and only an occasional viable seed thereafter. None of the

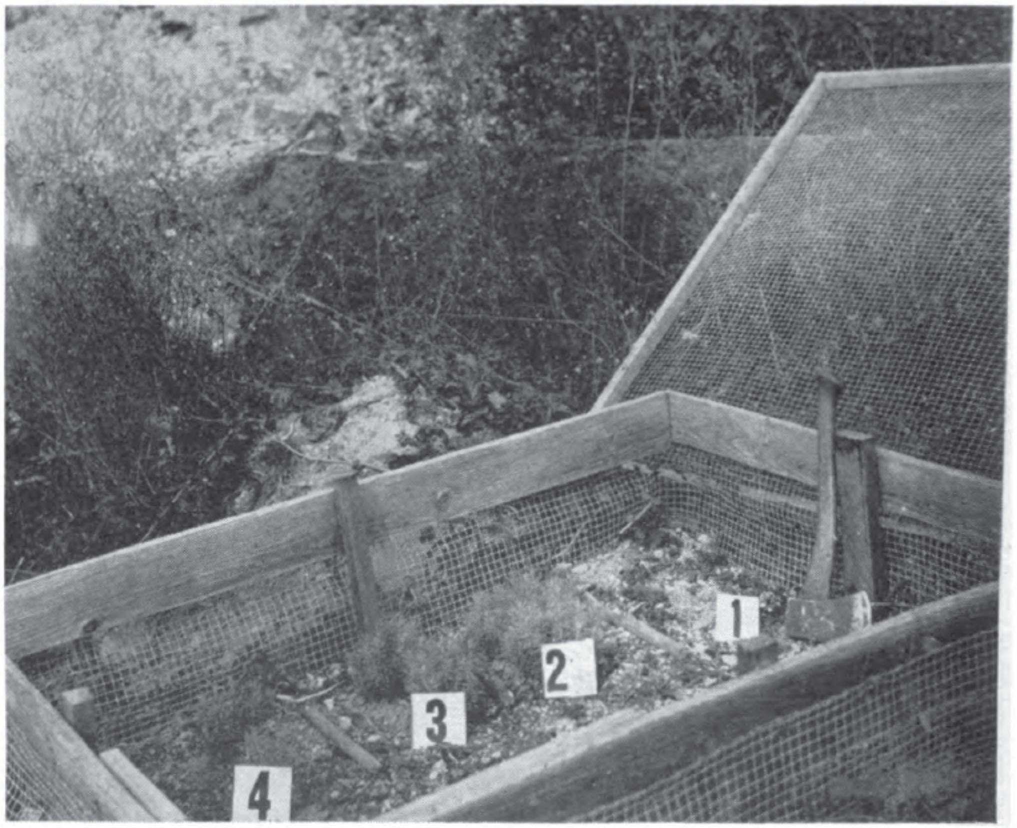

PLATE 3.—The life of seed after it falls was studied by placing seed in the forest floor and testing it for germination from 1 to 4 years later. Seed container No. 1 has been removed from the rodent-proof enclosure for the first-year germination test—note that seed germinated in place and seedlings are developing over containers Nos. 2, 3, 4.

seed of any of the other species retained its viability longer than the normal 1-winter period.

Studies by the writer of the germination on sample plots in various parts of the region during the past 15 years indicate that the number of fresh seedlings fluctuates with the cone crop of the previous year. Abundant seedlings are found following good seed years and few, if any, seedlings following seed crop failures. The studies[11] of the regeneration on the Tillamook burn 2 and 4 years after the fire showed conclusively that the seedling crop of Douglas-fir, hemlock, and spruce was directly correlated with the cone crop of the previous year.

Altogether there is conclusive evidence that Douglas-fir seed does not commonly retain its viability for more than a year after it ripens. There may be conditions in nature under which Douglas-fir seed is germinable for more than a year, but the evidence is now very strong that the amount is too small to be a factor in reforestation, and forest managers should not count upon seed surviving on the forest floor more than a year.

[11]Isaac, L. A. and Meagher, G. S. Natural reproduction on the Tillamook burn two years after the fire. Pacific Northwest Forest and Range Experiment Station. 19 pp., maps. March 5, 1936. (Mimeo.) Natural reproduction on the Tillamook burn four years after the fire. Pacific Northwest Forest and Range Experiment Station. 15 pp. January 10, 1938. (Mimeo.)

SEEDLING ESTABLISHMENT

It is proverbial that many seeds have to fall on a burned or cut-over area for every seedling that becomes established. The ratio of seeds to seedlings varies greatly because of differences of topography, soil, weather, ground cover, and animal depredators. Where each of these conditions is favorable a dense stocking of seedlings may result from a single normal seed crop; where any one or two of these conditions is very unfavorable almost no seedlings may become established. Even under generally favorable circumstances, a considerable portion of the seedlings that germinate are killed during the first few years by adverse weather or soil conditions, or by rodents, insects, birds, or fungi. It is not uncommon to find in the Douglas-fir region areas of logged-off land that are nonstocked or poorly stocked with reproduction even within range of numerous seed trees. This is in contrast to the very excellent restocking that is seen frequently under seemingly similar conditions. The explanation must be found in the several environmental factors that affect the seedling during its early life. Some of these conditions may be controlled or affected by the forest manager; others are fixed. It is important to have a knowledge of the role of each of these factors on seedling establishment.

Douglas-fir germination starts with the beginning of growth of most of the common vegetative cover species on cut-over land and continues for several weeks. Like many other plants it varies with seasons and altitudes. Bracken fern, one of the most common plants on cut-over land, starts growth a couple of weeks later than Douglas-fir seedlings during normal seasons, but during a late spring both break through the soil surface at about the same time. During a 6-year period on one particular cut-over area at an altitude of 1,500 feet, the beginning of germination was noted to vary from the last week in April, in an early spring, to the second week in June, in a late spring. In the same general locality, but under virgin timber cover where the temperature averaged about 10° F. lower than it did in the open, the beginning of germination occurred about one month later than it did in the open.

Generally speaking, altitude affects germination to the same extent that it affects climatic conditions; germination has been noted to be well under way at low altitudes in warm valleys while cut-over areas at a 3,500-foot elevation were still under snow. This season of germination can be of vital importance in seedling establishment. Late germination may cause seedlings to be caught by late frosts or early hot spells before seedling hardiness or cover has developed; on the other hand, late germination may occur after the last killing frost or the first severe hot spell.

Douglas-fir seed germinates best on mineral soil, whether fine or coarse, provided there is sufficient moisture. Seed will also germinate on duff or other surfaces provided there is sufficient moisture and warmth, but the seedling must eventually get its roots down to mineral soil to survive and thrive.

Previous investigators (*3*) (*10*) (*11*) (*12*) working with Douglas-fir and associated species, have noted the high mortality and hazards of seed-

ling establishment which sometimes destroy an entire seedling crop. Hofmann (*12*) points out that "the dry slopes and ridges were barren or very sparsely stocked, and the moist valleys and north slopes were well stocked."

Environmental Factors Affecting Seedling Establishment

The factors affecting seedling establishment of Douglas-fir have been studied at various points in the region, but particularly in a series of observations begun by the author in 1924 (*17*) at the Wind River Experimental Forest north of Carson, Washington.[12]

In order to appraise quantitatively the effect of various environmental factors on newly germinated seedlings, one phase of these Wind River studies, begun in 1927 and continuing for six years, consisted of very detailed observations of environmental factors and their effect on Douglas-fir regeneration on three areas similar in topography, soil, and original forest type, but differing in present cover, as follows:

1. Cut-over area, slash burned in 1925 so severely that most of the debris and duff was consumed and subsequent vegetative cover was established very slowly. This area was typical of severe site conditions following logging and burning.
2. Brush-covered cut-over area, lightly slash burned in 1920. It is typical of less severe site conditions following logging.
3. Virgin timber consisting of a 1,000-foot strip that is located between number 1 and number 2.

For convenience in the following discussion the first area will be called "open," the second "brushy," and the third "virgin timber."

Records were taken on each area of maximum and minimum air and soil temperatures, evaporation, and solar radiant energy, rainfall, soil moisture, influence of shade, root penetration, wilting point, effect of soil color, and of the causes of all seedling losses.

These studies were directed especially to determine the exact cause for the high mortality of Douglas-fir seedlings during their early years, which was already well recognized. Since natural reproduction was exceedingly scarce on these areas, seed was sown in spots in order to have sufficient material to observe. The seed spots were screened against rodent depredations. When a seedling appeared above the ground it was staked, given a number, and note made of the soil in which it occurred and the shade it received. It was watched regularly and a record made of its condition and probable cause of death, if it died.

Temperature, especially surface soil temperature, both maximum and minimum, was found to be the environmental factor most critical to the early survival of the seedling. While recognized as influencing growth and soil drying, subsoil temperatures at 3-, 6- and 12-inch depths were not found to be directly connected with seedling losses.

Maximum Temperatures

Air and subsoil temperatures both contribute toward drought and thus indirectly are the causes of seedling deaths from lack of moisture, but high

[12]The results of some of these studies, particularly the early phases, were reported in U.S.D.A. Circular 486 "Factors affecting establishment of Douglas fir seedlings" by L. A. Isaac, which are here briefed with the addition of data from subsequent years of study.

surface soil temperatures kill young seedlings directly. When exposed to high temperatures, seedlings up to two or so months old, while still succulent, develop a white spot on the stem, or heat lesion, which eats into the stem and causes the seedling to collapse at the ground level and topple over. The stem is literally cooked and the cell structure broken down at the ground surface. Newly germinated Douglas-fir seedlings showed the first indications of heat lesions when the surface soil temperature was 123° to 125° F. Considerable variation was found in the resistance of individual seedlings of the same age, and some hardened and developed resistance more quickly than others. A few survived surface soil temperatures of 160° during the latter part of their first summer. It is perhaps a safe conclusion that Douglas-fir seedlings in their first few weeks cannot ordinarily withstand a surface temperature over 125°.

The relation between air temperature and surface soil temperature is naturally not constant, so it is not easy to predict the surface temperature from a reading of the air temperature. Much depends on atmospheric, soil, and cover conditions.

Figure 3 shows for various air temperatures the average surface soil temperature and the surface soil temperature at two standard deviations above and below the average calculated from data taken in gray-colored soil on the open area during the first 3 years of the study. This graph indicates, for example, that at an air temperature of 85° F. the surface soil temperature averages about 133°, but may range anywhere between 105° and 155° in 95 cases out of 100.

Shade, both high and low, from living vegetation and "dead shade" from stumps and logs affects surface soil conditions greatly. In the virgin timber area, surface soil temperatures averaged very little greater than air temperatures—3° F. In the "open area" when the air temperature was 80° and the surface soil temperature on an open spot was 123°, under a nearby dogwood bush the surface soil temperature was only 90°. In fact, the surface soil temperatures under brush shade never did average 115° and never reached the danger point (125°) except occasionally when shafts of sunlight fell directly over the thermometer bulb for a considerable period.

Slope and exposure also have a pronounced effect on surface soil temperature and thus on seedling survival. A comparison of maximum surface soil temperatures during a 35-day period in late summer 1931 on the Wind River Valley floor with that on the surrounding hills, all in full sunlight, shows the following significant differences: The valley floor temperatures averaged 143° F., the south exposure 150°, the east exposure 147°, and the northwest exposure 137°.

The color of the soil is another factor that may affect surface temperatures enough to be of vital importance in seedling establishment. When the surface temperature of the natural gray soil of the open study area was 123° F., that of the same soil blackened by the addition of the charred remains of burned slash and duff was 130°—7° higher, both with an air temperature of 80°. With an air temperature of 100° the difference was 15°—148° for the gray surface and 163° for the blackened surface. On a yellow mineral soil on the same area the surface soil temperatures averaged 5° cooler than those on the natural gray surface.

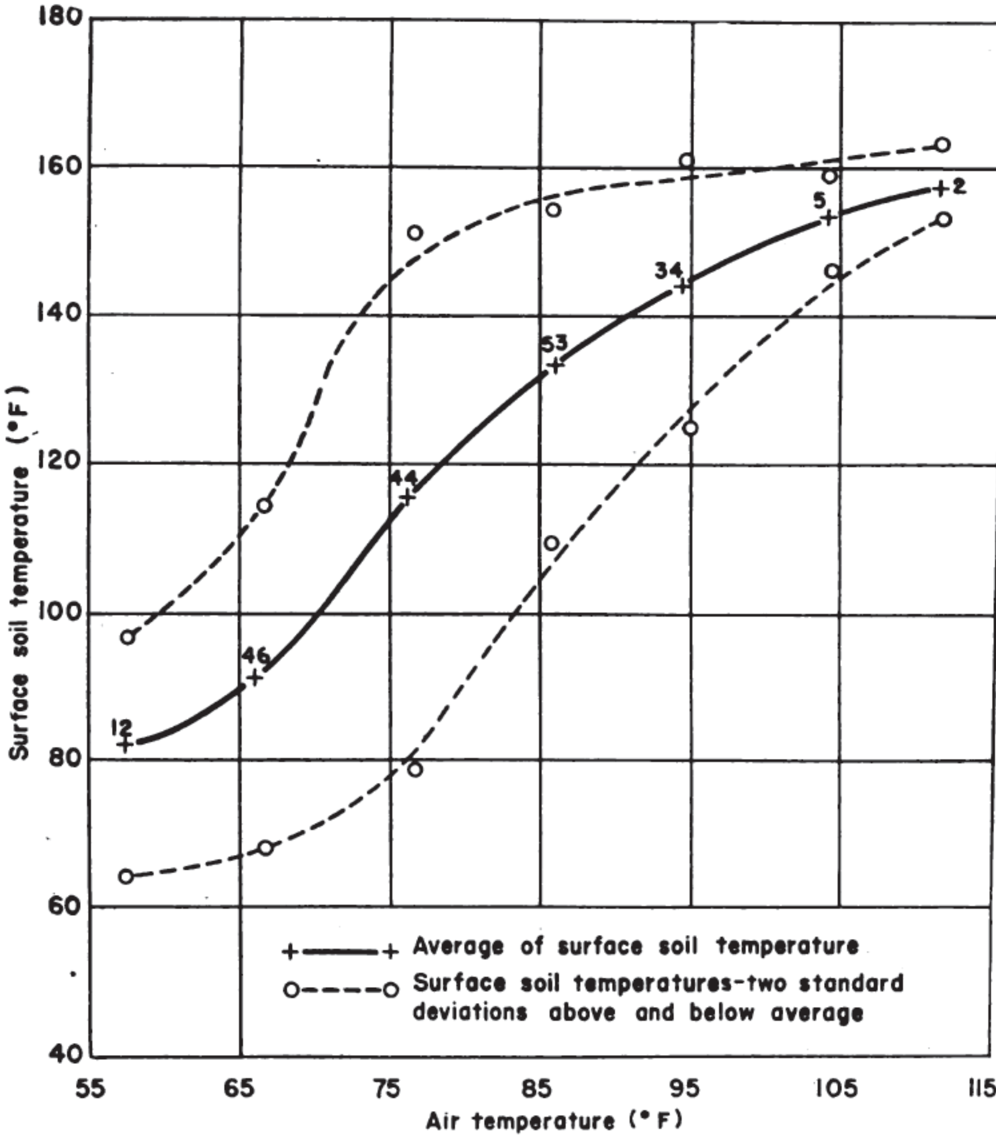

FIGURE 3. Range of daily maximum surface soil temperatures that occurred at different maximum air temperatures. Curves drawn from records taken during summers of 1927, 1928, and 1929 on the open area in the Wind River study on a gray soil surface without shade.

An actual record of seedling mortality on these comparative surface soil conditions was obtained in 1929 while temperatures were being taken among newly germinated seedlings. One day in May, the air temperature rose to 89° F., the yellow soil showed 125° and many seedlings were injured but not killed, while on the blackened soil the temperature rose to 143° and 47 per cent of the seedlings died. On the next four days the surface temperature on the yellow soil rose to 137° and 32 per cent of the seedlings died and others were injured, while on the blackened soil, it rose to 144° and all the remaining seedlings died. A 100 per cent loss as compared with a 32 per cent loss in a 5-day period forcefully illustrates the

importance of a few degrees difference in surface temperature, and how surface soil color alone may make enough difference in surface temperature to be a critical factor in seedling establishment.

The above discussion of the role of maximum temperatures helps to account for the occasional absence of natural reproduction even in the presence of a seed supply and under conditions of soil and moisture that appear favorable. It is apparent that damaging temperatures, depending as they do upon the incidence of hot days in the early part of the growing season, are closely correlated with exposure, shade, soil color, and perhaps other interrelated factors.

Minimum Temperatures

Minimum temperatures, particularly minimum surface soil temperatures, were found to be one of the important causes of seedling losses in the Wind River Valley, and this observation is thought to be of general application in the region wherever spring frosts occur. Twice (1930 and 1932) during the 6 years that the study was under way, losses were sustained from this cause. Others have reported losses of young seedlings and planted stock by frost damage to foliage, but in this study losses were confined chiefly to direct frost injury to the succulent stem of the seedling. Freezing appears to rupture the cell walls of the stem close to the ground surface, and in many instances results in an injury that is similar in appearance to, and difficult to distinguish from, heat injury.

The variation between minimum air temperature, taken in a weather shelter, and minimum surface soil temperature, taken on fully exposed mineral soil and under different types of shade, constitutes one of the significant findings in connection with the Wind River study. It was not determined at exactly what temperature frost injury occurs, but heavy losses were noted in one instance when the air temperature dropped to 29° F. and the surface temperature in the open dropped to 24°, and in another instance when the air temperature was 27° and the surface temperature 23°. These low temperatures occurred in May 1930 and May 1932.

Minimum air and soil temperatures in the open study area, in the brushy area, and in the virgin timber area are shown in Figure 4. It will be noted that when the air temperature was 30° F., the surface soil temperature under a dogwood bush was 32° and that under virgin timber was 33½°, while that on fully exposed mineral soil was approximately 26°. As may be seen by the diagram, such variations were comparatively consistent at air temperatures of 30° to 50°.

In addition to the frost injury to the stems of very young seedlings at the ground surface, frost damage and mortality to larger seedlings by direct injury to stem and foliage is not at all uncommon throughout the region. From time to time it is responsible for the failure of natural regeneration (and plantations as well) in frost pockets and exposed places. It may happen in late spring or early fall and even in midwinter when extreme cold suddenly follows warm, moist weather. The most recent severe damage occurred on May 25, 1940. Munger reports[13] frost damage at frequent intervals from Puget Sound south to the middle fork of the Willa-

[13]Munger, T. T. Frost damage. U. S. Forest Serv., North Pacific Region, Six Twenty Six 24(10):25-26. October 1940. (Mimeographed.)

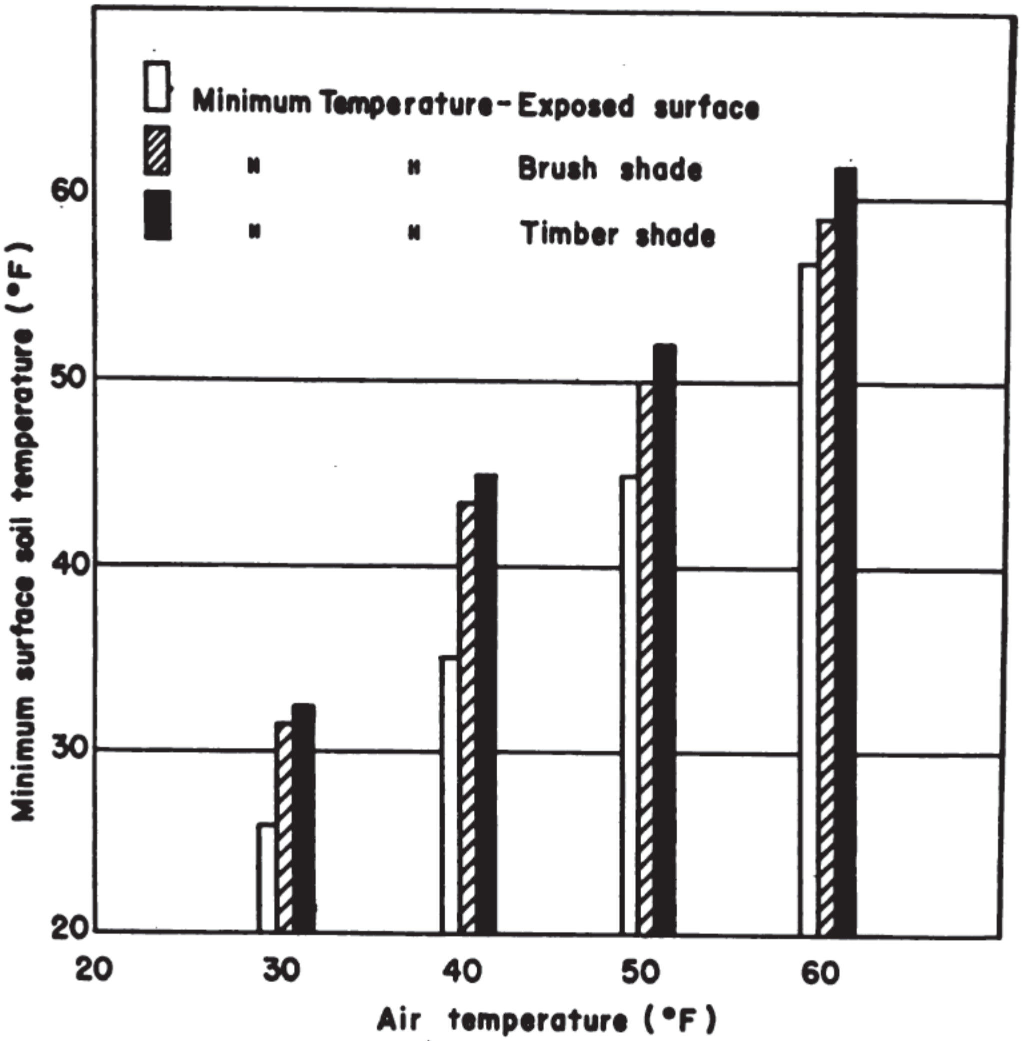

FIGURE 4. Average daily minimum air temperatures and corresponding average minimum surface soil temperatures taken on the open area, on the brushy area, and on the virgin timber area in the Wind River study.

mette River in Oregon. Sometimes the damage was in the zone 1 foot from the ground, and sometimes it extended to a height of 4 to 6 feet; small seedlings were killed outright. Lord[14] found damage most common on flat areas; sometimes only leaders and top laterals of seedlings and saplings were killed; occasionally even saplings were killed outright.

Evaporation and Insolation

In the Douglas-fir region, where there is a long period in the summer of cloudless and rainless days, often with low atmospheric humidity, the rate of evaporation and the intensity of insolation have an important bearing on the establishment and survival of tree seedlings. Observation

[14]Lord, Charles M. Frost damage to reproduction. U. S. Forest Serv., North Pacific Region, Six Twenty Six 24(9):18. September 1940. (Mimeographed.)

throughout the region shows that shade is beneficial to Douglas-fir seedlings through lessening evaporation, but only up to the point that lack of sunlight adversely affects the functioning of the young tree.

In the Wind River studies, intensive measurement of these factors was made jointly using white Livingston cup atmometers for comparative study of evaporation in various kinds of shade, and black and white atmometers, in pairs, to give a measure of insolation, or solar radiant energy or "light" under various cover conditions.

The importance of both evaporation and light are well demonstrated in the records of seedling establishment, though a definite measure of the importance of these factors in relation to others, such as temperature and soil moisture, was not obtained.

Evaporation.—Evaporation reflects the combined effect of temperature, relative humidity, and air movement and together with precipitation and soil moisture, determines drought conditions. Since drought is one of the major causes of seedling loss, it is important to evaluate evaporation in studying seedling establishment.

The general trend of evaporation during the summer season at Wind River is well indicated by the records for 1929 shown in Figure 5. The average daily evaporation under dogwood brush shade is 36 per cent less and under virgin timber shade is 44 per cent less than in the open. Evaporation under the shade of fireweed and bracken was found to be proportionally higher than under the more dense shade of brush and virgin timber.

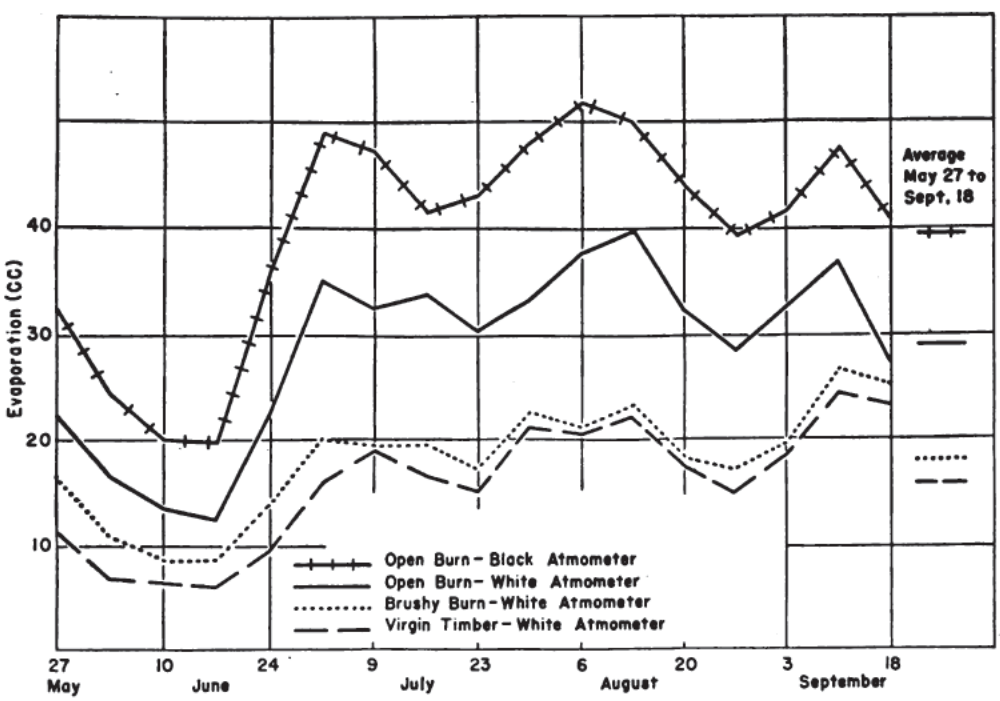

FIGURE 5. Average daily evaporation for each week during the summer of 1929 on the "open," "brushy," and "virgin timber" areas in the Wind River study. The trend of evaporation during this season was typical for the six years that the study was under way.

The consistently higher rate of evaporation in the open area than in the brushy area is striking, averaging 28 cc. daily from the atmometer for the former and only 18 cc. for the latter.

Naturally the surface soil zone on fully exposed areas is robbed of its moisture at a more rapid rate than usual when the evaporation rate is high. However, on surfaces shaded by weeds and brush, the increase in transpiration from vegetative cover must almost equal the increase in evaporation on exposed surfaces, because the soil moisture was found to be very nearly equal on all three areas (see section "Precipitation and Soil Moisture"). During periods when the evaporation rate is high, the rate of transpiration from seedlings in the open appears to increase to a point where the roots are not capable of supplying enough moisture to the plant, and wilting or drought loss occurs even though there is sufficient soil moisture to support seedling life under shade or under more normal evaporation rates.

The seedling that is suffering from drought first turns slightly yellow, its needles curl upward, and then it turns brown. Drought injury usually occurs late in the season, and by that time most seedlings have hardened sufficiently to remain in an upright position when dead. However, should drought losses occur early in the season, the seedlings may tumble over as they do when suffering from heat or frost injury.

Insolation.—Insolation, as determined by noting the difference in evaporation between black and white Livingston cup atmometers, gives a measure of shade densities, and in addition an indication of the difference in evaporation from a black and a white surface.

Insolation has a direct influence on plant activity, but it has a further effect on the rate at which soil and slash dry out. The difference in rate of evaporation from black and white atmometers is at least some indication of the difference in the rate at which slash and soil with black, charred surfaces would be robbed of their moisture, as compared with the bleached, gray surface of unburned slash or the lighter color of unburned soil surface. Figure 5 shows an approximate average daily evaporation of 40 cc. from a black sphere and 28 cc. from a white sphere both under complete exposure to the sun, or 43 per cent greater for the black; this is practically the same as the 6-year average. Records taken during 1930 indicate that under the shade of dogwood brush, the evaporation from a black sphere was 30 per cent above the white, while under virgin timber the black was but .9 per cent above the white. The decided reduction of solar radiant energy by the brush shade was not surprising, but the reduction to about 2 per cent of full sunlight by the shade of a normal site III virgin Douglas-fir forest was greater than expected. Two per cent of full overhead light is below the minimum requirement for Douglas-fir seedling survival, as will be shown later in the discussion of partial cutting and the effect of overhead shade on Douglas-fir regeneration.

Wilting Point of Douglas-fir Seedlings

The majority of seedling loss is known to occur during the first summer following germination; therefore, root penetration and wilting point observations were confined to current year seedlings in the Wind River study. Root penetration of these seedlings on the open area was found to be from 3 inches to 12 inches, but the soil zone from 2 to 7 inches below

the surface contained most of the feeder roots on a majority of the seedlings.

The wilting point of current year seedlings was fixed by determining the soil moisture content at which permanent wilting took place. It was found to vary with weather conditions and with individual plants. Permanent wilting occurred in separate tests at soil moisture contents that varied all the way from 5 to 12 per cent of oven-dry weights of soil, but the average moisture content at which wilting occurred in this soil was approximately 10 per cent. This is considered the danger line for this soil, even though some wilting did occur on sample plots during hot, dry periods when soil samples indicated a moisture content of 12 per cent, and some seedlings continued to live during periods of mild weather when the soil moisture content fell considerably below 10 per cent.

Precipitation and Soil Moisture

The annual precipitation in the Douglas-fir region is in general high, in parts of the region very high, in comparison with other coniferous forest regions, but its distribution throughout the growing season is not well suited to maintaining an adequate amount of soil moisture for the establishment of seedlings. During the summer months, precipitation is very light in parts of the region; in some years, July and August are practically without any rain. Since loose and porous soils prevail over much of the region, the lack of summer rainfall becomes an important element in seedling survival.

The intensive studies at Wind River determined the seasonal trends of soil moisture and the water content of soils of various depths under the three types of cover. Conditions of local climate and soil will, of course, make differences in the water content of soil, but the Wind River Valley can be considered to be fairly representative of that portion of the region where the soils are light and the summer days are dry, sunny and hot. Though the annual precipitation here is 85 inches, the summer season rainfall averaged for the years 1927-33 as follows: May, 2.20 inches; June, 2.03; July, .38; August, .35; September, 2.82. Three of the six Julys had no precipitation. Such rains as do occur in the summer are usually light and are partly intercepted by vegetation. One series of measurements (in 1931) showed that while 6.51 inches of rain fell in the open, 4.85 inches reached the ground on the brushy area, and 4.51 under the virgin forest. Rains of less than a tenth-inch seem to do no more than wet the crown canopy of the virgin forest or of the brush.

Weekly soil moisture determinations, taken at different depths on the three study areas, are shown for the year 1929 in Figure 6; they are typical for the other years in the 6-year period. A summation of the measurements for the whole period of the study shows that at the 3-inch depth there was the most soil moisture under the timber, the least in the open; that at the 6-inch depth the moisture content was very nearly the same on all areas; and that at the 12-inch depth the highest moisture content was found in the open area.

Each year the trend of soil moisture content is downward from early summer until the autumn rains start—except for fluctuations associated with rains or short periods of excessive surface drying. Toward the end

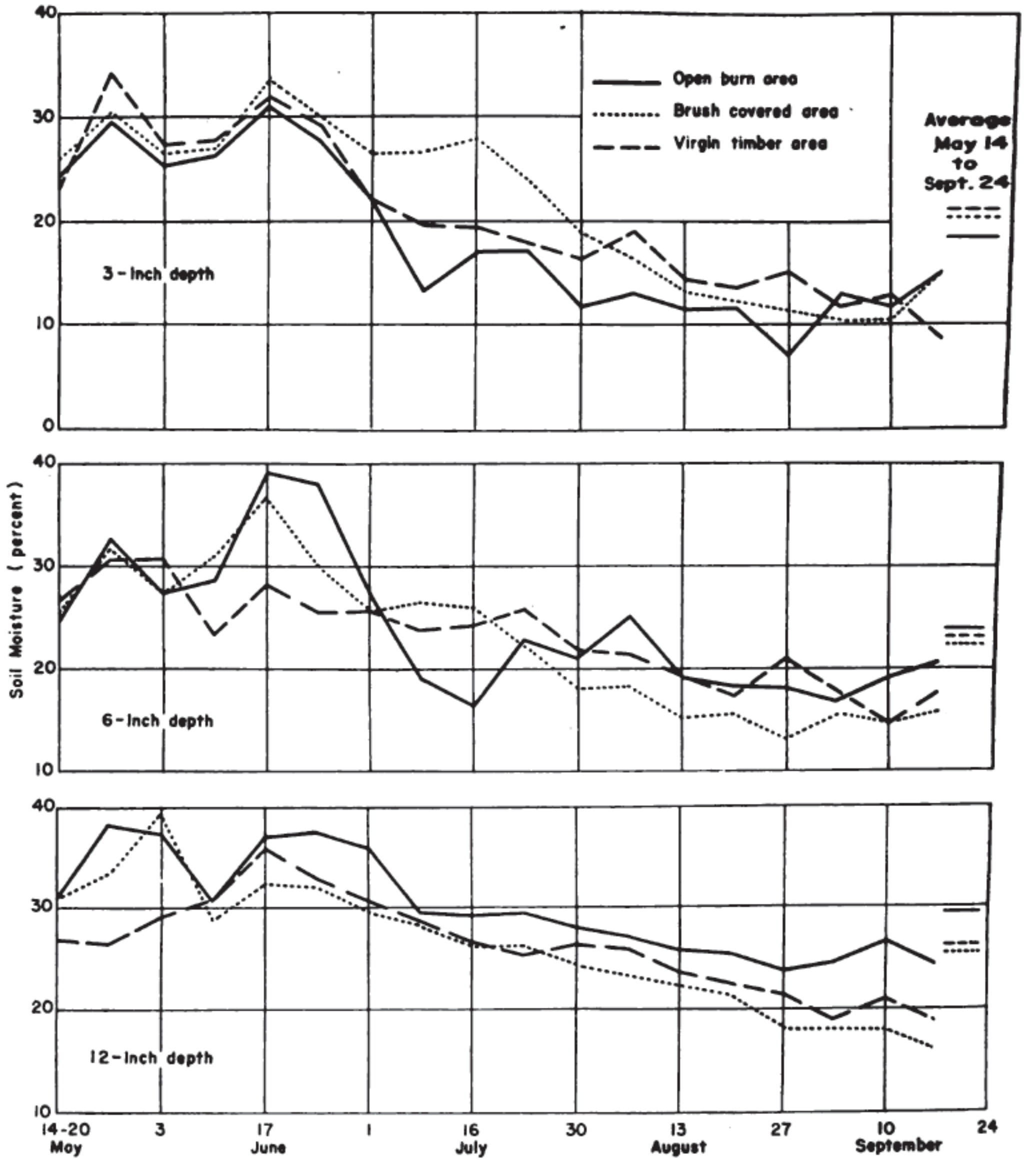

FIGURE 6. Weekly soil moisture record in per cent of oven-dry weight at 3-, 6-, and 12-inch depths on the "open," "brushy," and "virgin timber" areas for the 1929 season in the Wind River study. The relationships between areas and the general downward trend were typical for the 6 years that the study was under way.

of the summer at the 3-inch depth, and occasionally at the 6-inch depth, it approaches or falls below the danger point for seedlings—10 per cent for the soils of this area.

Except for very short periods following rains, the soil moisture was greater at a depth of 12 inches than at 3 or 6 on all areas. This indicates that the water which supports seedling life during the summer drought is soil-stored and not current rainfall. This is the reverse of findings in other forest regions where frequent summer rains occur or where there is a higher humus content in soil zones occupied by seedling roots.

When the moisture contents at the 3-, 6-, and 12-inch depths for each area for all years of the study were averaged it was found that there was but little difference between them; the soils of the open area had a 22.1 per cent moisture content, those of the brushy area 21.2 per cent, and those in the virgin timber area 22.4 per cent of oven-dry weight.

The movement of water in the soil, particularly upward (because so little falls on the surface in the summer) is important to the life of shallow-feeding seedlings. A continuous film of water on soil particles from moist subsoil upward is necessary for the upward movement of moisture. Comber (*6*) says: "Where the water table is high and the film above it is comparatively thick, the removal of water by evaporation at the top of the film will cause some water to creep up to restore the equilibrium." To determine whether or not the Wind River soil would follow this principle, a test was made in 1937 with 3 pairs of 6-inch glazed tiles, 2 feet long, filled with packed soil and set in tubs of saturated soil; 1 set was filled with "dry" soil (10 per cent moisture content) and the other with "moist" soil (16 per cent moisture content).

One pair was removed at weekly intervals, and the moisture content of their soil measured at the 7-, 15-, and 23-inch point above the saturated soil in the tub. The findings of this test are presented in Table 3.

A soil moisture of 10 per cent, as in test "A," the average wilting point for the Wind River soil, was considered "dry," a 16 per cent moisture content, as in test "B," was considered "moist" for it supported seedlings well; a 45 per cent moisture content was the highest field moisture recorded and was considered saturation.

TABLE 3.—WEEKLY CHANGE IN SOIL MOISTURE CONTENT, IN PER CENT OF OVEN-DRY WEIGHT IN TUBS AND IN TILES AT 3 POINTS ABOVE SATURATED SURFACE

	Test "A" Dry Soil				Test "B" Moist Soil			
	8/13	8/20	8/27	9/3	8/13	8/20	8/27	9/3
22-24 inches above base[1] (Top 2" layer of soil)	10	5	5	8	16	13	11	14
14-16 inches above base (8-10" below surface)	10	11	11	11	16	21	21	24
6-8 inches above base (16-18" below surface)	10	15	16	16	16	24	24	26
In tub at base	38	38	38	38	51	51	51	51

[1]The base is the point at which the column of dry soil in the tile rests on the saturated soil surface in the tubs.

The "dry" soil (10 per cent moisture content) in the 3-weeks' period lost moisture in the top 2-inch layer, gained only 1 per cent in the upper 8- to 10-inch layer, and only 6 per cent in the upper 16- to 18-inch layer. The moist soil (16 per cent) also lost moisture in the top 2-inch layer, but at the 8- to 10-inch depth gained 5 per cent the first week and 8 per cent by the end of the third week, and at the 16- to 18-inch depth it gained 8 per cent the first week and 10 per cent by the end of the third. In other words, it became very moist to within 8 inches of the surface and remained that way.

This simple test demonstrates that the rise of moisture in soil to replace loss due to evaporation is related to the degree of saturation of subsoil, and

the amount of moisture in the soil through which more moisture is to rise; and that once the upper layers get dry, the rise of moisture in this soil is almost negligible, in much the same manner as moisture rises through a wet wick but fails to rise through a dry one.

From these studies it is evident that either long periods of drought that would exhaust the supply of moisture in the subsoil, or short periods of excessively hot, dry weather that would quickly dry out the surface soil zone to a point where it could no longer take up moisture from below, may separately or jointly become the limiting factor in seedling establishment and survival.

Mortality from Diseases and Insects

Seedling losses from damping-off fungi are common throughout the country in coniferous nurseries and have also been noted in natural regeneration. Hofmann (*13*) reported in 1924 serious losses of Douglas-fir seedlings in this region. Later, Haig (*10*) reported heavy losses of Douglas-fir and other conifers in the Northern Rocky Mountain region. The author noted heavy losses of Douglas-fir seedlings in the virgin forest from damping-off during 1926-27 in studies of germination, and has since noted occasional loss on natural reproduction plots in widely scattered parts of the region; however, no losses whatever were noted from this cause on the 4-year study (*17*) (1928 to 1931) in the Wind River Valley. The disease thrives in a cool, damp, or shady environment and, therefore, is not common on open clear-cut areas.

The shoestring rot (*Armillaria mellea*) is the only important widespread disease affecting established Douglas-fir seedlings. It is a fungus that travels in the soil and attacks the seedling at the root collar. It may kill trees singly or in a patchwise pattern. Losses have been recorded on sample plots in widely scattered parts of the region and also in well established plantations.

The two most important insect enemies of Douglas-fir seedlings are strawberry weevils (*Brachyrhinus* spp.) and cutworms (*Noctuidae*). They are common in coniferous nurseries and are observed sometimes in natural regeneration (*20*) but only rarely cause serious loss.

Mortality from Rodents and Other Animal Life

Douglas-fir seedlings from the time they come through the ground until they are several years old are subject to the depredations of animal life of various kinds. Mice consume the very young succulent seedlings, birds peck the seed coats off the expanding cotyledons of germinating seedlings, grouse eat buds and tender seedling tips, rabbits and mountain beaver cut off and gnaw the stems of older seedlings. Small birds were not observed in this study in the act of killing seedlings, but are a menace in nursery beds, and probably are a real though inconspicuous destroyer of seedlings in nature. No quantitative measure of the losses to natural seedlings from the larger rodents are at hand, but it is undoubtedly considerable. Planted stock of Douglas-fir suffers greatly—50 per cent or more—at times from rabbits and mountain beaver.

In the Wind River study there was a good opportunity to observe the destructiveness of mice. In May 1930 when germination was well under

way, the screen covers were removed from the seed spots, and within a few days half of the young seedlings were consumed by white-footed mice (*Paramuscus maniculatus austerus*). They nipped the seedlings off a fraction of an inch above the ground and ate part or all of them. The losses were checked by the spreading of poison; otherwise, the mice might have consumed the entire seedling crop. This mouse is a nocturnal feeder and may exist in great numbers without being noticed; it increases in number with almost unbelievable rapidity when weather and food conditions are favorable, as they evidently were in this year when they were far more destructive than on any other of the 6 years of the study.

Damage to Reproduction by Frost Heaving and Mechanical Injuries

Douglas-fir seedlings up to 3 years old are often killed by what is known as "frost heaving" as noted by other investigators (*11*) (*13*). It is common on clean burned or bare mineral soil surfaces. When a wet spell is followed by cold nights, a crust is formed of ice and surface soil particles, then ice crystals continue to form in the excessive moisture at the soil surface and push the ice crust upward. This action pulls the seedling out of the ground entirely or strips the roots and bark to the extent that the seedling is killed. No actual counts are available, but the actual process has been observed by the author both in the nursery and under natural conditions. On the first spring examination of reproduction plots throughout the region, it was not uncommon to find seedlings that sprouted on bare soil, heaved out of the ground and lying flat on the surface.

A discussion of the establishment of Douglas-fir natural regeneration would not be complete without mention of losses from mechanical causes. These are very variable in nature and intensity, and no quantitative measure of this class of damage to very young seedlings is at hand. Bark and branches falling from snags and trees and the trampling of animals take some toll, but the most serious in hilly topography is probably the erosion or creeping of loose soil which undermines young plants. As seedlings grow into saplings they become subject to snow and ice breakage, which cripples more trees than it kills outright.

Summary of Seedling Mortality for the Wind River Tests

Newly germinated seedlings are tender and are subject to death from a variety of causes; these causes change greatly in severity from year to year and vary with factors of shade, soil condition, exposure, etc. These facts are demonstrated in Tables 4, 5, and 6, which summarize the observations of first-year mortality on some 3,000 seedlings on the Wind River open and brushy study areas for the period 1928-33. Data for second- to sixth-year mortality are shown later in Table 7.

Data for seedling mortality on the virgin timber area is not included because the relatively few seedlings germinating here all died before they were more than about 6 weeks old, apparently from an excess of shade or failure to reach the moisture-bearing soil before the dry season; moreover, they germinated here about a month later than on the cut-over areas.

Table 4 indicates that, on the average, heat is the greatest single cause of loss, with drought next. It is significant that the causes fluctuate from year to year, heat from 66 per cent to zero, and causes other than heat or

TABLE 4.—CAUSES OF FIRST-SEASON MORTALITY OF SEEDLINGS GERMINATING FROM 1928 TO 1933, ON THE OPEN AND BRUSHY AREAS

	Loss in Per Cent of Total Germinated by Causes			
	Heat	Drought	Other[1]	Total
	Per Cent	Per Cent	Per Cent	Per Cent
1928 seedlings	48	21	4	73
1929 seedlings	62	12	12	86
1930 seedlings	0	13	82	95
1931 seedlings	0	66	0	66
1932 seedlings	24	19	44	87
1933 seedlings	40	29	15	84
Average	33	22	28	83

[1]"Other" includes losses from frost, rodents, insects, competition and mechanical injury.

drought from 82 per cent to zero. It should be understood that seedling death may be due to a combination of causes; where drought was the final cause of loss in the latter part of the season, it was so recorded even though the plant may have been previously weakened by other causes.

Table 5 shows how significant shade is to early survival. The seedlings in the open suffered 93 per cent losses, while those in dense shade only 43 per cent. This principle was evident every year, though there was range in mortality rates from year to year, particularly in the dense shade—from 20 to 80 per cent.

Table 6, relating causes to amount of shade, shows, as would be expected, that heat losses have an inverse relationship to the amount of shade. Drought losses are highest in medium shade, and losses from other causes are about the same in all degrees of shade. The heaviest loss of seedlings from drought under medium and dense shade can be ascribed to the fact that a larger percentage of the tenderest and late-germinating seedlings in the open are killed off early in the season by heat, frost, and rodents, before the dry season begins.

In view of the fact that these Wind River studies of first-year establishment of seedlings show no survival under the full canopy of virgin timber, and only a 7 per cent survival on cut-over land completely exposed to the sun, it is obvious that somewhere between these extremes must lie the optimum condition of shade for seedling survival. The records on the open

TABLE 5.—RELATION OF SHADE TO FIRST-SEASON MORTALITY OF SEEDLINGS THAT GERMINATED IN 1928 TO 1933 ON THE OPEN AND BRUSHY AREAS EXPRESSED IN PER CENT OF SEEDLINGS THAT GERMINATED

Year	Amount of shade			
	None	Medium	Dense	Total
	Per Cent	Per Cent	Per Cent	Per Cent
1928 seedlings	92	70	20	73
1929 seedlings	94	86	29	86
1930 seedlings	100	97	80	95
1931 seedlings	90	57	31	66
1932 seedlings	91	84	24	87
1933 seedlings	92	80	52	84
Average	93	79	43	83

TABLE 6.—FIRST-SEASON SEEDLING MORTALITY BY CAUSES IN RELATION TO AMOUNT OF SHADE FOR ALL SEEDLINGS GERMINATING ON THE OPEN AND BRUSHY AREAS FROM 1928 TO 1933

	Amount of shade			
	None	Medium	Dense	Total
	Per Cent	Per Cent	Per Cent	Per Cent
Per cent of total seedlings germinated	61	25	14	100
Loss by heat	45	23	0	33
Loss by drought	20	29	18	22
Loss by frost and other causes	28	27	25	28
Total dead	93	79	43	83
Total alive	7	21	57	17

and brushy areas show a 21 per cent survival under medium shade, and a 57 per cent survival under a "dense" shade of brush or debris. However, the seedlings involved were on prepared seed spots where they were somewhat free of the close proximity of root competition of other vegetation. Under natural conditions where the soil was not disturbed in making the seed spot, it is probable that the element of competition would enter in more strongly.

Seedlings growing on bare ground in the shade of logs or slash were found to survive better than those living in the shade of living vegetation (Plates 4 and 5). The shade of logs or slash—"dead shade"—keeps the hot sun from the plant without offering competition for plant food, moisture, and growing space, while living vegetation does compete with seedlings starting beneath. Furthermore, evaporation from the soil is retarded by a covering of logging debris.

Ideal conditions for early survival appear to be ample growing space for root and stem yet shade enough to protect against midday sun and night frosts. If this protection is furnished by logs and debris, it will continue to be favorable for later survival and growth, but if it comes from living vegetation, it will be likely to hamper the seedling's ultimate survival and growth.

In the foregoing discussion of Tables 4, 5, and 6, and particularly the effect of shade on seedling losses, the open area and the brushy area have been considered jointly. Naturally, a larger percentage of the seedlings were without shade on the open area than on the brushy area. In 5 out of 6 years the losses on the former were double those on the latter, and in the 1 year when the losses weer heavier on the brushy area, it was because most of the seedling crop there was consumed by mice. Whether the lead in survival on the brushy area will be reduced by the competition of shrubs and herbaceous vegetation in the years to come remains to be seen, but there is already a noticeable reduction in height growth on the brushy area.

The rate at which reproduction becomes established on cut-over lands in relation to various types of cover is shown later by a record of widely distributed sample plots; further data on height growth of the Wind River seedlings is also presented later.

Mortality of seedlings continues after the first season, but at a greatly

PLATE 4.—Eight seedlings marked by wire pins germinated on a bare, shady spot under the north end of this log in the Wind River study area; all were alive 5 years later, while most of the seedlings growing in complete exposure or in serious competition with other living vegetation had succumbed.

lessened rate. During the 6 years that the Wind River study was under way, second-year losses have ranged from zero to 9.0 per cent of the total germination and averaged about 1 per cent thereafter. It appears that if first-year losses are heavy only sturdy seedlings remain and losses in succeeding years are apt to be below the average, and the reverse would be true if losses the first season were light. Table 7 gives the mortality

TABLE 7.—LOSSES IN THE 1928 SEEDLING CROP FROM THE FIRST TO THE SIXTH YEAR AFTER GERMINATION UNDER DIFFERENT SHADE DENSITIES ON BOTH THE OPEN AND BRUSHY STUDY AREAS

Year	Amount of shade			Weighted
	None	Medium	Dense	Average
	Per Cent	Per Cent	Per Cent	Per Cent
1928	92.0	69.0	20.0	73.0
1929	6.0	9.0	12.0	8.0
1930	0.5	4.0	0.0	2.0
1931	0.0	0.4	4.0	1.0
1932	0.0	1.2	3.0	0.9
1933	0.0	1.6	4.6	1.3
Total dead October 1933	98.5	85.2	43.6	86.2
Total living October 1933	1.5	14.8	54.4	13.8

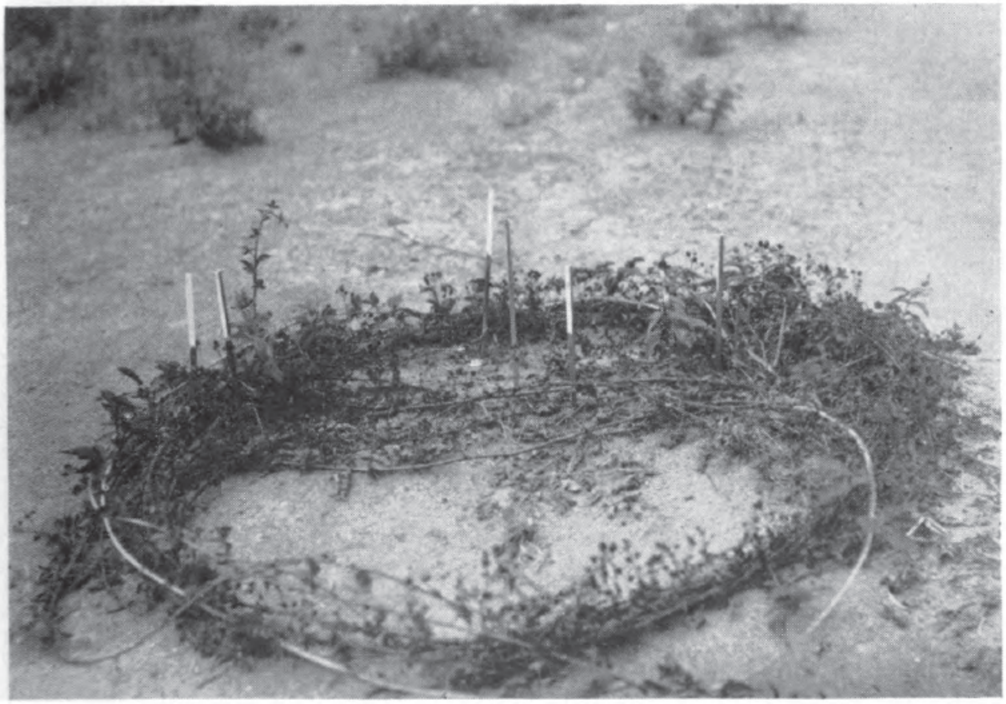

PLATE 5.—Five Douglas-fir and two Sitka spruce seedlings marked by stakes became established from natural seedfall in a 2-year period in this 4-foot circle of trailing blackberry vines, while no seedlings at all became established on surrounding bare soil. This illustrates the beneficial effect of partial shade without too much root competition.

by years from 1928 to 1933 for the 1928 seedling crop according to intensity of shade on the open and brushy cut-over areas. The losses after the first season were relatively higher in the shade, an important consideration, though there were many more survivors after 6 years in both medium and dense shade than in the shadeless spots. Since the first season loss of 1928 seedlings was 10 per cent less than the average for all years, it is reasonable to suppose that the 13 per cent subsequent loss (averaged for all degrees of shade) is higher than average. Though the detailed record is available for only 6 years, losses will probably continue at a diminishing rate, up to the time that seedlings begin to crowd each other for growing space.

A comparison of the day-by-day weather with the seedling loss record (as is done in a previous report by the author (*17*)) shows notable peaks of mortality with extreme meteorological conditions of one sort or another. For example, in the latter part of May 1929 when germination was at its height, there was a hot, dry spell of weather creating surface soil temperatures in exposed spots of 138° F. This caused a loss of 63.4 per cent in just a few days prior to May 25, and an additional 3.2 per cent during the next few days on the open area. With cool moist weather in June there was almost no more loss. As the summer drought increased and the soil moisture at the 3-inch depth approached 10 per cent, a mortality of 14.4 per cent ensued, which with a 12 per cent loss from rodents and insects gave a 93 per cent loss for this open area that year.

The losses on the nearby brushy area are quite different from those on the open area in the same season, because there the effect of extreme weather varies so with cover and other conditions. On the brushy area the seedlings suffered only a 17 per cent loss from heat (in contrast to a total of 66.6 per cent on the open area). On the other hand, drought took a heavier toll on the brushy area; this is perhaps partly due to the fact that on the open area the least well established seedlings had been killed off by heat, while on the brushy area there had not been so much natural selection of the fittest.

The rise and fall of seedling mortality with the occurrence of extremes of weather shows that there is a considerable element of chance in Douglas-fir establishment. If the spring and early summer is free of extremely hot weather or unseasonable freezes, the seedling crop may come through without heat or frost losses. During a wet summer a higher percentage of the young plants will become established than during a dry summer, and the contrast will be more marked on severe sites.

RELATION OF CLIMATE TO DOUGLAS-FIR REGENERATION

Within the Douglas-fir region of western Oregon and western Washington, there is a wide range in the climatic conditions under which this tree regenerates satisfactorily and forms dense forests. The range in precipitation is from about 20 inches (on the northeast end of the Olympic Peninsula) to well over 100 inches on the coastal strip and on the upper slopes of the Cascade Range. At the lower altitudes nearly all falls as rain, while at the higher altitudes much of it comes as snow, illustrating the range in temperatures. For the better forested portion of the region as a whole, the precipitation is upwards of 50 inches.

Extreme temperatures of over 100° F. and below zero are experienced in localities where the tree forms splendid forests, though its foliage is sometimes parched by extreme cold and dry winter winds in exposed situations. Some points in the region are free of killing frosts for close to 300 days a year, while other parts of the region may have a killing frost any month in the year. Late spring freezes not infrequently blight the new foliage of Douglas-fir, especially in "frost pockets," and kill young seedlings, though this is not thought to be a prohibitive factor in the regeneration of Douglas-fir anywhere in the region under discussion. Winds severe enough to blow down patches of timber occur occasionally here as in other forest regions, but they are not a delimiting factor in forest development, except in a few windswept exposures. The prevalence of high winds in some areas is thought to be an important cause for extra widespread seed dissemination and regeneration of certain clear-cut areas.

The most important element of site quality, used as an index of growth potentialities, is climate. Though tolerant of a great range in precipitation and temperature, Douglas-fir does not grow equally well under all conditions. It is very responsive to variations within certain limits. It makes its best growth under a combination of a long growing season, sufficient heat, and heavy precipitation. Conditions favorable for growth are apparently also favorable for regeneration.

From north to south in this region there is a progressive increase in the intensity of insolation and temperatures and a decrease in the precipitation for equal altitudes. Douglas-fir reflects that climatic difference by its absence on south exposures in the southern part of this region. This is partly due to the difficulty of regeneration on the southerly hot, dry slopes, partly to competition of brush. Likewise on the narrow strip close to the coast, Douglas-fir gives place to hemlock and spruce, possibly because the site is too foggy and cold for its successful regeneration and growth, and partly because of competition. On the high mountains (above 3,000 to 4,000 feet in Washington and 4,000 to 5,000 feet in Oregon) the

Douglas-fir type is replaced by a stand of balsam firs, mountain hemlock, and other trees tolerant of cold and short growing seasons; not that individual Douglas-firs will not survive there, but they will not regenerate and grow satisfactorily enough to compete against the real mountain-loving trees.

As is shown elsewhere in this paper, local variations in climate have a very profound effect on regeneration of Douglas-fir. There may be more difference to the individual germinating seedling between a north and a south slope or between a frost pocket and a well air-drained area than between the climate of the coast and the Cascade region or between that of Oregon and Washington. These are the variations which the practicing forester must recognize and reckon with. Within certain limits—which are very broad for Douglas-fir—the important practical considerations of the effect of climate on regeneration have to deal with the very local, or micro-climatic, variations of heat, cold, insolation, evaporation, and moisture.

RELATION OF SOILS TO DEVELOPMENT OF REGENERATION

Douglas-fir becomes established on a great variety of soils and is not fastidious as to the texture or chemical composition of the soil within the limits found in this region; however, it avoids swamps and lands subject to overflow. Western Washington and Oregon have a great variety of soils; rocky loam soils, both shallow and deep, are common in the Cascade Mountains; there is an extensive area of coarse gravel in the Puget Sound region; on the Coast Range particularly are clays and clay loams; in the valleys and foothills deep alluvial soils of a great range in texture are prevalent; and quite commonly within the forested regions are loose, sandy loams composed partly of volcanic pumice and sand. On all of these Douglas-fir establishes itself—provided other factors are hospitable—and develops good forest stands. Nevertheless, the soil quality greatly affects the rate of growth of forests just as it affects growth of agricultural crops, though rainfall and length of growing season are perhaps still more important. It is a matter of record that reproduction occurs in more dense stands on the poor, gravel soils in the Puget Sound region and rocky soils elsewhere than it does on the rich loam or clay soils. But once established the seedling on the better soil may make from 2 to 3 times the height growth of seedlings on the gravel soil. Three reasons are offered for the more dense stocking on the gravel soils: First, heavier seed production; second, smaller crowns and greater root penetration in loose soil; and third, less competition from secondary vegetation.

Importance of Surface Soil

Depth of soil and character of subsoil, while important factors in determining site quality and the rate of growth of established trees, are of less significance in the regeneration of Douglas-fir than the surface layers of the soil. Under virgin timber the surface of the mineral soil is covered by a layer of humus or fibrous duff that averages about 1½ inches in thickness exclusive of sticks and rotten logs. This consists of needles, leaves, twigs, cones, bark scales, and herbaceous plant material; it is in all stages of decomposition, from fresh, recently deposited material on the surface to a thin layer of crumbly, black, fully decomposed humus in mixture with the upper layers of mineral soil. The fact that this layer of organic material is usually not more than 1½ inches thick indicates that conditions are favorable for decay under the timber cover, and that during the life of the stand (usually terminated by fire or logging or both) decomposition very nearly keeps pace with deposition. In the cold, high mountain country and the cold, moist coast country where conditions for decay are not favorable, duff is sometimes much thicker.

The organic content of the mineral soil is usually low and decreases as the depth increases. The nitrogen content occasionally amounts to 1 per cent (of dry weight) in the fibrous duff layer, but usually is not more than one-tenth of 1 per cent in the mineral soil below.

Usually the soils of the Douglas-fir region are highly acid, with *p*H values frequently as low as 4.0 in the surface layer, and seldom as high as 7.0 even at lower depths. The moisture-holding capacity of virgin forest soil is greatest in the duff-humus layer, and diminishes gradually with depth in the mineral soil because of a gradual decrease in amounts of organic and fine mineral material.

The most important available soil nutrients—nitrate-nitrogen, phosphorous, potassium, and calcium—are naturally most prevalent in the surface layers, and, like the organic material, they are greatly diminished and well diffused in the mineral soil. The nutrient-forming duff layer acts as a continuous source of supply of plant foods through decomposition.

Cutting of the forest upsets conditions through exposing the surface soil to sunlight and mixing duff with mineral soil. If followed by slash burning it brings about a revolutionary change; the fire consumes a great deal of the organic material, drives off nitrogen, and reduces acidity and moisture-holding capacity. If not too severe, fire may temporarily make more plant food available; but it usually destroys much nitrogen and cuts off the source of further supply through destruction of the duff layer and the soil micro-organisms in it. It also leaves the mineral constituents in changed or dehydrated form and breaks down the crumb structure in the rich surface-soil zone.

Results of Slash Burning on Wind River Soils[15]

For a test of the effect of slash burning on forest soils, a freshly logged area in the Wind River Valley was selected (*19*). The soil was a loose "shot" loam representative of a type common in the region. In the early fall, when the moisture content was near the low point, samples were taken for physical and chemical analysis both where the slash was light and heavy. A month later after the rains started the area was burned. The highest temperatures recorded were 1841° F. at a point just above the ground surface and 608° an inch below the surface in duff and mineral soil. Soil samples were again taken at the same spots and analyzed. The effects of slash burning upon the soil may be summed up as follows:

Heavy slash burning reduced the organic matter in the duff layer from 88.53 per cent (in relation to dry weight) to 9.72 per cent, and in the 0- to 3-inch soil layer from 5.69 to 3.54 per cent. Correspondingly, the total nitrogen content was reduced, but in the duff layer only.

The loss of the organic matter affects seedling development not only through loss of nitrogen, but also because of its influence on the moisture-holding capacity of the soil. The maximum moisture-holding capacity of the duff layer after the fire was only a half of that for an equal amount of duff before, and the "field capacity" for moisture retention only a third as great after the burning. In the 0- to 3-inch zone the moisture-holding capacity was definitely reduced; below that the changes were not significant. In the duff layer the fire not only consumed three-quarters of the total

[15]A full account of the test, briefed here, carried out in cooperation with Washington State Agricultural Experiment Station, represented by Professor L. C. Wheeting, may be found in an article by Leo A. Isaac and Howard G. Hopkins, "The forest soil of the Douglas fir region and changes wrought upon it by logging and slash burning." Ecology 18 (2):264-279: April 1937.

volume of material, but it reduced the moisture-holding capacity of that which remained to a half of its former capacity.

Rough calculations indicate that the organic matter in a 1-inch duff layer (exclusive of rotten logs) weighs approximately 28 tons to the acre and that 25 tons of this is consumed by the slash fire; with this is driven off 435 pounds of nitrogen to the acre. The 25 tons of duff consumed has a moisture-holding capacity of nearly an inch of rainfall. In addition to the loss of much of this moisture-conserving layer, the capacity of the remainder and of the 0- to 3-inch soil layer to absorb moisture is greatly reduced.

Slash burning of the duff and organic matter in the soil drives off the carbon and some of the nitrogen and leaves an ash, which makes immediately available certain mineral plant foods—at the same time creating some very unfavorable soil conditions. Just what per cent of the mineral nutrients, or the compounds in which they occur, are lost when the duff is burned was not determined, but it is evident that there is a loss because the increase of nutrient concentration in the ash is far from proportional to the decrease in total amount of organic material. However, it is probable that this loss is confined to the duff layer and the upper soil zone. It is presumed that there is a loss of calcium, potassium, phosphorous, etc., in the smoke through the mechanical action of the up-draft of the fire.

In addition to loss of mineral nutrients by slash burning, a source of future supply is cut off since the duff layer forms the reservoir in which mineral nutrients are constantly being made available through microbial activity. There is also the loss of mineral nutrients after fire, particularly in steep country, through washing and leaching, since there is usually little erosion-retarding vegetation the first season or two after a fire.

The final result of a slash fire on mineral nutrients appears to be a higher concentration of calcium, potassium, and phosphorous in the surface soil immediately after the fire, but this favorable result is offset by a substantial reduction in the total amount of these substances and also the destruction of the duff layer in which they are made available.

Soil Acidity

Slash burning tends to change, temporarily at least, the duff and surface soil from an acid to an alkaline condition, but how long this change continues is not known. In the tests at Wind River the duff layer was *p*H 4.95 before burning and 7.6 after, and the 0- to 3-inch layer changed from 5.0 to 6.2. Below 6 inches there was no change, and the fact that there were rains between the "before" and "after" sampling probably accounts for the influence of the fire going even that deep.

A slightly acid reaction appears to be favorable for Douglas-fir seedlings, though at times when the Wind River Nursery soil happens to be neutral, the trees seem to make as good growth as when it is slightly acid.

However, the "sweetening" of the soil, or the higher concentration of plant nutrients that results from burning, or a combination of the two, appears to stimulate the growth of certain competing herbaceous plants such as fireweed, senecio, and bracken during the first year or two following the slash fire. Seedlings may also benefit from the concentration of plant nutrients but only those that occur the first year or two, as the nutrients are in such soluble form that they are soon leached away.

Relation of Soil Condition to Seedling Development

Logging and slash burning make changes in the surface soil both favorable and unfavorable to Douglas-fir seedling establishment, but the damage to the physical conditions undoubtedly far outweighs the temporary chemical improvements. The reduction in moisture-holding capacity of soil is of vital importance in this region of summer drought. Also the losses of nutrients cannot help but reduce forest productivity in the long run. Intensely hot burning may so change the physical condition of the soil that seedlings cannot establish themselves, and even planted trees will not grow until the soil has regained some of its proper structure and texture.

A striking instance of the failure of planted trees to survive on certain very heavily burned spots in the Wind River Valley was intensively studied in 1928 (*19*). It was found that survival of 2-year-old planted trees was particularly low on spots where crossed logs or tree tops had made a very hot fire and the soil had been burned red. Rain falling on such spots puddled the surface, reducing its capacity to absorb water. Soil samples from these heavily burned spots and from adjacent lightly burned spots were analyzed by soil scientists at Washington and Oregon State Experiment Stations. These analyses showed, for the heavily burned soil, depletion of the nitrogen supply, breakdown of the colloidal structure, dehydration of the secondary minerals, and a more or less complete destruction of the organic matter. It was predicted that weathering would restore the structure of the mineral soil to something like its former state in 5 years, but that the restoration of the nitrogen and organic matter would take many years.

Small trees were replanted on these severely burned spots and again died, but after several repetitions the survival of replacements increased and by the fifth year practically full survival was attained. The Douglas-fir planted trees on the heavily burned spots, however, did not make good growth and even after 10 years their foliage was of a sickly yellowish color in contrast to the deeper green foliage of the trees planted on normally burned areas close by.

This observation of planted trees is very eloquent proof that extra-severe burning changes the soil structure and content to the extent that it is temporarily unsuited to Douglas-fir regeneration. It is conceivable that medium-heavy burning may make the soil somewhat less hospitable to seedlings than no burning, but not in a way that is so easily observed or demonstrated as the above instance, because of the interplay of other factors.

RELATION OF COMPOSITION AND DENSITY OF VEGETATIVE COVER TO REGENERATION

The importance of shade to Douglas-fir seedlings is illustrated in the summary of seedling mortality for the Wind River tests. It is pointed out that seedlings flourish in light shade, and that "dead shade" furnishes protection while the slash or debris furnishing it does not compete with the seedlings for plant food and moisture, as is the case when shade is produced by living vegetation. This so-called living shade soon becomes competition and combines with other factors to retard regeneration. Munger (*27*) in 1911 wrote: "If brush has 2 or 3 years' start over the tree reproduction, it is almost impossible for Douglas fir seedlings to become established in competition with it."

Just what are the trends of vegetative succession after logging? At what point is a further increase in density harmful to seedlings? What are the most favorable cover plants? These are the problems with which we are confronted.

Vegetation Succession After Logging

Throughout the Douglas-fir region there is in general a luxuriant development of brush and herbaceous ground cover after logging. This is often heavy in the mature and overmature forest, but is temporarily reduced to almost nothing by the logging and slash burning. The root parts of some species of undergrowth survive the clear-cutting process, while other species of weeds and brush invade the cut-overs, creating commonly a rank and dense thicket of a variety of plants growing 1 to 10 feet high. This reaches its heaviest density sometime between the date of burning and the closing of the crown canopy of the new forest stand. During this stage, cover has a profound effect upon the development of Douglas-fir seedlings. When the young forest has formed a closed canopy (at about 10 to 30 years of age), the herbs and shrubs are shaded out and reach their low point and remain so for several decades until the forest canopy begins to thin.

The rate of development of this herbaceous and brushy cover after logging is influenced by site quality, intensity of slash fire, repeated burns, species present, and annual weather variations; it appears to follow certain trends of succession, but no definite laws of rate of development or species composition (*21*).

A record is available (*18*) of the vegetative cover following logging and slash fires for 15 groups of sample plots from 1926 to 1933, expressed by species in per cent of total cover; the locations of these plots are shown in Figure 1.[16] Freshly slash-burned areas were selected for this study, but a limited number of the plots fell on unburned spots; also some plots have

[16]The data here presented expand the discussion of the same series of observations that were described in an earlier article by the author, "Vegetative succession following logging in the Douglas fir region with special reference to fire." Jour. Forestry 38(9):716-721, September 1940.

TABLE 8.—VEGETATIVE SUCCESSION IMMEDIATELY AFTER LOGGING IN THE DOUGLAS-FIR REGION. REGIONAL DISTRIBUTION OF SPECIES IN PER CENT OF TOTAL COVER AND FREQUENCY OF OCCURRENCE

	Per cent of cover				Frequency of occurrence in per cent of areas occupied			
	1926	1928	1930	1933				
Average density of total cover—all areas	35.4	79.4	73.6	73.9	1926	1928	1930	1933
Herbaceous plants in per cent of total								
Groundsel (Senecio vulgaris)	29.6	.1	.9	.0	87	20	27	13
Willow herb (Epilobium spp.)	5.3	5.5	.5	.1	67	67	40	33
Bedstraw (Galium spp.)	.6	.3	.2	.2	40	40	40	40
Miner's lettuce (Montia spp.)	2.0	.2	.0	.0	53	7	7	7
Fireweed (Epilobium angustifolium)	8.5	24.4	21.5	18.0	80	93	100	100
Fall dandelion (Leontodon spp.)	.2	7.4	9.5	3.8	13	66	80	66
Peavine (Lathyrus spp.)	.8	3.2	4.0	2.7	33	53	60	60
Sword fern (Polystichum munitum)*	3.2	2.0	1.6	1.6	80	73	80	80
Woodsorrel (Oxalis oregana)*	1.4	1.1	.9	.5	33	67	67	60
Starflower (Trientalis latifolia)*	2.4	.8	1.2	1.4	33	60	73	87
Bracken (Pteridium aquilinum)	7.3	9.2	9.4	11.4	66	80	93	100
Pearl everlasting (Anaphalis margaritacea)	.5	.8	1.5	2.3	40	40	80	93
Hawkweed (Hieracium albiflorum)	.5	.4	.9	1.4	40	40	73	87
Grass	2.0	3.2	2.8	3.4	33	67	73	80
Total herbaceous plants	64.3	58.6	54.9	46.8				
Brush in per cent of total								
Trailing blackberry (Rubus macropetalus)	5.3	8.7	9.0	8.5	93	100	100	100
Snowbrush (Ceanothus velutinus)	.3	.3	1.7	2.3	13	20	20	33
Blackcap (Rubus leucodermis)	.1	.2	.1	.1	20	33	47	60
Blueberry elder (Sambucus glauca)	2.5	1.1	1.0	1.0	80	73	73	67
Oceanspray (Holodiscus discolor)	.3	.2	.3	.3	27	40	47	40
Red flowering currant (Ribes sanguineum)	.2	.2	.5	.8	27	40	60	67
Nootka rose (Rosa nutkana)	.9	1.0	1.0	.9	60	80	80	80
Snowberry (Symphoricarpos spp.)	.1	.3	.3	.5	13	27	33	33
Salal (Gaultheria shallon)*	5.4	9.1	12.1	13.8	73	87	87	87
Oregon grape (Mahonia spp.)*	3.8	5.0	5.7	7.0	80	93	93	93
Whortleberry (Vaccinium spp.)*	.6	1.0	1.1	1.3	53	60	93	93
California hazel (Corylus californica)*	.6	.0	.8	1.0	27	27	27	27
Vine maple (Acer circinatum)*	3.7	2.9	3.0	3.9	80	73	80	80
Salmonberry (Rubus spectabilis)*	1.0	1.6	2.2	2.4	13	40	47	47
Total brush	24.8	32.2	38.8	43.8				
Miscellaneous species and coniferous seedlings	10.9	9.2	6.2	9.4				
Total	100.0	100.0	100.0	100.0				

*Indicates virgin forest species, others are invaders.

been reburned since establishment. They represent a wide range of conditions in western Washington and northwestern Oregon; but they do not cover that portion of the Douglas-fir region where evergreen, dry-site shrubs are dominant, as in southwestern Oregon. These are the so-called "semipermanent" plots upon which seedling records were taken and are given in a later section.

These records show that 14 of the most important herbaceous plants and 14 of the most important brush species make up over 90 per cent of the total cover on these plots. The frequency of occurrence and per cent of total cover represented by these 28 species are shown in Table 8.

A great number of species, in addition to those listed in the table, were recorded and were included under the caption "miscellaneous species"; in some localities certain of these miscellaneous species made up a considerable portion of the cover.

Immediately following the slash fire there is a pioneering stage of vegetative development that includes certain mosses and liverworts. This stage is skipped on areas that are not burned. The weed and brush stage that follows includes, along with coniferous seedlings, species from two sources, namely, species from the original forest whose underground parts survived the logging and slash fire and invading species that did not occur in the shade of the original forest.

Since the occurrence of species is erratic and often accidental, the combining of records from widely scattered areas may average out many sudden and significant changes in the life cycle of certain short-lived plants; some of these are shown by individual plot records in Tables 9 and 10. Table 8, however, is valuable in furnishing definite data on per cent of total cover, frequency of occurrence, and general trends of development for the most widely distributed important species. This table indicates that during the first year the herbaceous cover amounts to 2½ times that of the brush

TABLE 9.—Cover Record of an Individual Sample Plot Near Wilark, Oregon, Burned Only Once in 1925 After Logging, Showing Typical Sudden Changes in Composition and Density of Herbaceous Species, Particularly Groundsel, Fireweed, and Bracken

	1926 Pct.	1928 Pct.	1930 Pct.	1933 Pct.	1936 Pct.
Density of total cover—all species	30	85	80	85	85
Herbaceous plants in per cent of total					
Groundsel (Senecio vulgaris)	35	----	----	----	----
Fireweed (Epilobium angustifolium)	35	90	70	15	5
Bracken (Pteridium aquilinum)	----	2	10	65	75
Pearl everlasting (Anaphalis margaritacea)	10	2	10	3	3
Hawkweed (Hieracium albiflorum)	----	----	2	2	2
Sword fern (Polystichum munitum)	----	----	----	2	2
Woodsorrel (Oxalis oregana)	10	----	2	3	3
Total herbaceous plants	90	94	94	90	90
Brush in per cent of total					
Trailing blackberry (Rubus macropetalus)	----	----	2	2	2
Blueberry elder (Sambucus glauca)	10	2	----	3	3
Whortleberry (Vaccinium spp.)	----	2	2	2	2
Salmonberry (Rubus spectabilis)	----	2	2	3	3
Total brush	10	6	6	10	10

TABLE 10.—COVER DEVELOPMENT ON A CUT-OVER AREA NEAR WILARK, OREGON, THAT WAS SLASH BURNED IN 1925 AND REBURNED IN EARLY 1929 AND AGAIN IN 1933

	1926 Pct.	1928 Pct.	After 2nd burn 1929 Pct.	1932 Pct.	After 3rd burn 1936 Pct.
Density of total cover—all species	42	82	22	78	58
Herbaceous plants in per cent of total					
Groundsel (Senecio vulgaris)	10	----	----	----	1
Willow herb (Epilobium spp.)	----	----	----	2	----
Fireweed (Epilobium angustifolium)	----	----	----	4	2
Sword fern (Polystichum munitum)	10	3	1	2	----
Bracken (Pteridium aquilinum)	37	25	92	50	52
Pearl everlasting (Anaphalis margaritacea)	----	----	----	2	5
Grass	----	7	1	4	2
Total herbaceous plants	57	35	94	64	62
Brush in per cent of total					
Trailing blackberry (Rubus macropetalus)	7	14	2	4	11
Snowbrush (Ceanothus velutinus)	----	1	----	----	6
Nootka rose (Rosa nutkana)	----	1	----	----	1
Salal (Gaultheria shallon)	25	35	1	14	11
Oregon grape (Mahonia spp.)	10	11	1	12	5
Whortleberry (Vaccinium spp.)	----	2	1	4	2
Total brush	42	64	5	34	36
Miscellaneous species	1	1	1	2	2
Total	100	100	100	100	100

cover. Then there is a gradual decrease in the per cent of herbaceous cover and a gradual increase in the brush until by the end of the eighth year they constitute about equal per cents of the total cover. This battle for possession continues with the odds constantly in favor of the brush, unless interrupted by fire or unless both are suppressed by the new oncoming coniferous forest (Plate 8).

The total cover usually reaches its first peak in density at about the third year, because of the rapid development of annuals and perennials that have wind-blown seed and thrive in the ash of the slash fire; then as these decline or disappear there is a slight drop in cover density until they are gradually replaced by the more lasting perennials and the gradual growth of the woody shrubs. Cover on individual plots and sometimes on whole areas approaches a density of 100 per cent, but the highest average reached for any one of the entire group of plots was just under 80 per cent during the life of this study (Plates 6, 7 and 8).

Among the herbaceous species some annual plants like groundsel (*Senecio vulgaris*) come in promptly after logging and may form 90 per cent of the cover then disappear in a single year; others like the willow herb (*Epilobium* spp.) do not come in as heavily but last a little longer. Perennials like fireweed (*Epilobium angustifolium*), fall dandelion (*Leontodon* spp.), and peavine (*Lathyrus* spp.) usually increase in density for a period of 3 to 5 years, then start to decline. Sword fern (*Polystichum munitum*) and woodsorrel (*Oxalis oregana*) are examples of herbaceous species that hold over from the original forest and usually decline gradually

PLATE 6.—The cover of bracken, fireweed, and brush on this clear-cut, unburned area became so dense that it was practically impossible for Douglas-fir seedlings to become established.

from year to year. Pearl everlasting (*Anaphalis margaritacea*) and hawkweed (*Hieracium albiflorum*) are species that are quite well distributed over the region, but grow in small clusters and seldom form a large part of the cover. Bracken and some of the grasses, on the other hand, once started continue to increase in density until crowded out by more vigorous competitors. Bracken and fireweed by the eighth year comprised a higher proportion of the herbaceous cover than any other species and were the only two to occur on all the 15 areas.

The sudden changes in herbaceous cover, which may produce favorable or unfavorable conditions for seedling establishment but which do not show up in the averaged records for the region as a whole (Table 8), may be seen in the record of an individual sample plot (Table 9). The rapid development and decline of fireweed and the gradual continuous development of bracken is fairly typical on individual plots and sometimes on entire areas. But the time-of-occurrence element is of importance; for example, fireweed may come in on one part of an area, reach its peak, and start to decline before it will show up on another part of the same area.

Among the woody species, trailing blackberry (*Rubus macropetalus*) is the most common invader on cut-over land. It appears to thrive for a time then gradually declines as taller competitors come in. However, it averaged over 8 per cent of the total cover and was the only species to occur on all of the areas after the first year. Snowbrush (*Ceanothus velu-*

PLATE 7.—Douglas-fir seedlings occurring on unburned sample plot No. 13, Wilark area along with a normal ground cover of fireweed, blackberry, and other species 5 years after logging.

tinus) is another important invading brush species. While it does not occur on many areas or form a large percentage of the total cover, where it does occur it develops in a patchwise fashion forming such dense thickets as to crowd out other vegetative cover and coniferous regeneration as well. Salal (*Gaultheria shallon*) and Oregon grape (*Mahonia* spp.) are the most important and universal shrubs holding over from the original forest. Both are low-growing and occur patchwise, except that in the moist coastal country salal forms tall continuous thickets. Vine maple (*Acer circinatum*) and salmonberry (*Rubus spectabilis*) are important larger shrubs. The roots of the last four named species survive the slash fire, thrive during the weed-brush stage of succession and then often hold on and form part of the ground cover in the new forest.

Practically all of the common herbaceous and brush species will come in on cut-over land whether it is slash burned or not, but burning has a definite influence on the rate of development and the distribution. Seven of the areas studied were completely burned just before the plots were established and never reburned. Comparing the cover on these burned plots with that of the plots which had not been burned, it appears that in general in the region under discussion—western Washington and Oregon

north of the Umpqua-Willamette Divide—burning favors the herbaceous species that have wind-blown seeds and retards the woody[17] species. Successive fires repeat and intensify the effects of the first fire, and in addition kill all coniferous reproduction that has started and often kill the remaining seed trees. They usually further impoverish the soil (as discussed in a previous section) and tend to upset the weed-to-brush succession. The most noticeable result of repeated fires is a higher frequency of occurrence, but less luxuriant growth, of the deep-rooted perennials of which bracken is the most outstanding example; in fact, a heavy stand of bracken, or bracken to the exclusion of other species, is generally accepted as evidence of repeated fires except on the drier sites in southwestern Oregon.

Just how repeated fires favor herbaceous species, particularly bracken, at the expense of the shrubs is evident from the observations of part of a group of sample plots that were burned 3 times (Table 10). The percentage of herbaceous species, particularly bracken fern, was high after each successive fire, then declined as the percentage of brush increased. But because of the repeated fires, herbaceous species made up more than half of the total cover 3 years after the third fire and 10 years after the initial burn, and the percentage of brush had declined to about half of what it was 3 years after the first fire. The scattered seedlings that occurred on this area were either choked out by the vegetation or killed by successive fires, except on a small unburned spot that now has over 1,000 well established seedlings per acre.

In southwestern Oregon, where evergreen, dry-site brush species are common after fires and logging, it appears from general observation that repeated fires do not encourage the herbaceous species at the expense of the woody species, but quite the reverse; however, no specific data, based on detailed continuous observations and case histories, are available.

A number of exotic species have become established in forest areas, and a few are of sufficient importance to fire control and forest regeneration to be worthy of mention. Australian fireweed (*Erechtites prenanthoides*) is the most important herbaceous plant in this group. It is an ill-smelling, unpalatable plant closely related to the eastern *Erechtites hieracifolia;* it was brought to California from Australia in 1918, and has since spread well up the Oregon coast. It makes such rank growth on cut-over land that for a short period after logging it often crowds out all other native vegetation, including tree seedlings. Scotch broom (*Cytisus scoparius*) and gorse (*Ulex europaeus*), similar showy flowering shrubs from Europe, are beginning to occur in such thickets as to crowd out native vegetation, and also to become obstacles to fire control.

Because no measure was taken of seed fall on these reproduction-vegetative succession plots, and because of the spotty nature of the cover, it was impossible here to measure accurately the influence of cover density on seedling development or to tell just when cover became a limiting factor. However, some definite findings were made. Form of plant was found to be as important as per cent of cover in the matter of composition. Some plants have broad basal leaves and spreading, fibrous roots. These compete with coniferous seedlings for both ground space and light; the groundsel (*Senecio vulgaris*) and fall dandelion (*Leotodon* spp.) are typical ex-

[17]An exception is the trailing blackberry that comes in readily after fire.

PLATE 8.—This Douglas-fir plantation with 4 x 4 spacing began closing the crown canopy about the fifth year, and by the tenth year, when this photo was taken, it had practically crowded out inflammable competing vegetation and brush.

amples. Other plants have slender single stems and few deep roots of the rootstalk type that furnish little competition for the seedlings except for crown space and light. The bracken (*Pteridium aquilinum*) is a good example of this type. This species, when occurring in light or moderate density, is considered an excellent nurse crop for Douglas-fir seedlings.

A confirmation of the above conclusion is found in three sets of paired sample plots that were established by McCulloch[18] to measure the influence of bracken on seedling establishment. They were located in a burn on a southerly exposure with moderately heavy bracken cover, in the coast foothills west of Corvallis, Oregon. On plots cleared of bracken a total of 2,206 seedlings was found in 1938. The bracken was removed annually and in the spring of 1942, 1,503 seedlings were found on the plots—a loss of 703 seedlings or 35 per cent. On the undisturbed bracken-covered plots, a total of 1,357 seedlings was found in 1938 and 1,818 in 1942—a gain of 461 seedlings or 34 per cent. The increase in number of seedlings on the undisturbed plot may be due partially to the fact that it is all but impossible for the examiner to find the total number of seedlings on a bracken-covered plot, while the seedlings are small, without destroying the cover. Nevertheless, the fact remains that now (April 1942) there are more seedlings on the bracken plots than on the cleared plots, and those on the bracken plots are more thrifty in appearance and are making more rapid height growth.

In contrast to the above findings, in the same immediate vicinity spots were found where bracken cover had become so dense that in a long period of years it has not been possible for Douglas-fir seedlings to become established, even though there was an abundant seed supply. Such dense stands of bracken are common along the coast and on other moist, rich sites, but stands of light or moderate density are most common east of the Coast Range.

Brush species, like herbaceous species, vary in the amount of shade or competition they produce, but in general they produce heavier competition than the herbaceous species; some, like salal (*Gaultheria shallon*), spread out and in patches occupy ground space as well as crown space; others occur in clumps, like hazel (*Corylus californica*), and leave growing space for seedlings in the shade around them.

Because these variations exist in species mixture and nature of plants under natural conditions on cut-over lands, it was impossible precisely to determine the influence of cover on natural regeneration. However, in the field it was noted that seedlings became established neither in complete exposure to the sun nor in heavy shade of competing vegetation. When cover got beyond "moderate" density (60 to 75 per cent), seedlings were found chiefly in the more open spots where there was root and crown space; once established, however, seedlings often survived much heavier cover (Plates 6, 7 and 8).

[18]McCulloch, W. F. The role of bracken fern in Douglas-fir regeneration. Ore. State College, School of Forestry. 1942. Unpublished Ms. (Revised and published in Ecology 23(4):484-5.)

EFFECT OF OVERWOOD SHADE ON DOUGLAS-FIR REGENERATION

The effect of shade on seedling germination and establishment, especially the effect of low ground-cover shade and "dead shade" on maximum and minimum temperatures and evaporation, as well as on insolation, was discussed in an earlier chapter. So long as clear cutting alone was practiced, the only kind of shade that was important in Douglas-fir regeneration was the low shade of brush and the dead shade of logs and stumps. But with the growing use of tractors in logging and the practice of partial cutting, the high shade of the reserve stand is a potent factor in natural regeneration and may determine the species composition of the next crop, even to the exclusion of Douglas-fir.

It is a matter of common observation that no Douglas-fir saplings are ever found under the full canopy of a virgin stand, though young trees of the more shade-tolerant hemlock, cedar, and balsam firs are common. Furthermore, it is extremely significant that in the spring after every seed crop, germinating seedlings of Douglas-fir are abundant everywhere under the virgin forest cover and even under the densest of young stands of seed-bearing size. By fall, all these seedlings have disappeared because they cannot become established in the full shade of the mother forest. Douglas-fir seedlings must have enough overhead light not only to survive but also to compete successfully with the ground cover and the more tolerant and numerous seedlings of hemlock, et al. This has long been recognized. Allen in 1899[19] stated: "Fir seedlings do not start readily on humus and rotten wood, so that mere admission of light is not always sufficient for successful restocking of land. This is so, especially when hemlock is present to compete for ground, for hemlock much prefers a seed bed of organic matter and under such conditions is almost certain to get the mastery." Frothingham (*7*) in 1909 wrote: "Under heavy shade Douglas fir seedlings soon die out. With moderate overhead shade they maintain a slow, spindling growth for a number of years before they succumb. If released from overhead shade Douglas fir recovers. In the Coast region nearly all of its associates show greater capacity in this respect." Kirkland and Brandstrom (*22*) mention the necessity of group selection and clear cutting in the last stages of a cutting cycle in order to secure Douglas-fir regeneration.

Where a part of the canopy of a mixed old-growth forest has been removed, it is common to find an understory thicket of saplings and small poles, but they are of the tolerant species. Even on logged-off land in the shady margin of an old-growth forest, the species more prevalent next to

[19]See footnote 6.

PLATE 9.—A forest of Douglas-fir, cedar, and hemlock near Oakridge, Oregon, visited by fire 25 years before which killed trees in patches and made openings in the canopy.

A. Where the openings were small they filled with hemlock and cedar reproduction.

B. Where the openings were large they filled with Douglas-fir reproduction.

the timber is hemlock, the Douglas-fir not taking dominance until there is good overhead light. In "holes" in virgin forests (Plates 9A and B and Plate 10) when direct sunlight reaches the ground, Douglas-fir may become established and thus sometimes give rise in very old stands to uneven-agedness in a patchwise fashion, instead of the conventional even-aged stands characteristic of pure Douglas-fir forests.

PLATE 10.—An opening in a 64-year-old stand with full overhead light where Douglas-fir reproduction is becoming well established.

Observations on Reproduction Under a Partial Cover of Seed Trees

A measure of the effect of various degrees of shade from trees reserved from cutting upon Douglas-fir reproduction was made by Yocom and Hilsman[20] in 1941 on an area of national forest land near Rujada, Oregon, logged 18 to 23 years earlier. A considerable number of cull trees was left standing, more than enough for reseeding the tract. On the plots studied the number varied from 1 to 32 per acre, averaging about 14, 10 of which were still alive. The entire tract is now well stocked with Douglas-fir seedlings, but there is great difference in their height and thriftiness, depending upon the amount of overhead shade to which they have been subjected. Their height was found to vary from 2.5 feet on the plots where there was a large number of reserved trees to 13.4 feet where there were few overwood trees. Under the heavy cover of standing cull trees Douglas-fir seedlings germinated, developed weakly, or died and were replaced by others which likewise were unable to endure successfully in such shade. Competition of the overwood with the seedlings for soil moisture was also a factor, and is not considered subordinate to the competition for light. Seedlings in the open or light shade made excellent growth. It was usually found that the seedlings surrounding a single large seed tree made good growth regardless of their proximity to the big tree; it was only when there were two or more seed trees close together that the growth of the understory seedlings consistently was affected.

Mean annual height growth and the current season's height growth for 3 degrees of high shade are compared in Table 11.

TABLE 11.—Height Growth of Douglas-Fir Seedlings in Relation to Number of Reserved Trees in the Overwood

No. of Plots	Average number of large reserved trees per acre	Height growth: Mean annual (Inches)	Height growth: Current season's (Inches)
4	2.2	6.48	16.64
3	11.3	5.40	11.23
3	20.0	3.12	8.81

There was a noticeable slowing up of height growth when the number of reserved trees reached 11 per acre, and a pronounced difference when there were 20 or more per acre.

The residual stand of 20 defective large trees per acre constituted more than half the gross volume of the original stand and occupied more than half the crown space. In competition with this residual stand and the undergrowth of brush, Douglas-fir seedlings were not successful; had there been tolerant species in this forest, as there were not, they would no doubt have taken possession of the understory.

A Measure of Light Values Where Douglas-Fir Is Present Under Partial Cover

Douglas-fir and hemlock regeneration was found on an area within the Wind River Experimental Forest where half or more of the virgin forest

[20]Yocom, T. R. and Hilsman, V. J. Development of regeneration under cull trees left after logging in the Douglas-fir region. 1941. 24 pp. Ms.

PLATE 11A.—Three such 16 x 16-foot shade frames with ventilated sides and slat roofs were built for controlled shade studies. Seeds and transplants were planted in these under three different light intensities and observed for germination and survival.

had been killed by a crown fire in 1902. The reproduction varied from almost pure Douglas-fir to almost pure hemlock, but Douglas-fir definitely predominated in the larger openings. Light measurements made in 1937, with black and white atmometers, in places where Douglas-fir predominated, showed a light value of 64 per cent of full overhead light. Midday readings with a photometer indicated a light value of 45 per cent of full overhead light. There was no evidence that light conditions had changed since the 1902 fire, although it is very probable that some trees died immediately thereafter. On a few other areas in the region, Douglas-fir was found coming in under the remnants of an old stand, but no light measurements were made because in every instance the crown density was being reduced constantly by mortality or cutting, or the remnants of the old stand occurred singly or in patches with the Douglas-fir reproduction in the openings.

A Controlled Test of Light Requirements of Douglas-fir Seedlings

To measure the overhead light requirements of Douglas-fir regeneration under controlled conditions, a study was started at the Wind River Experimental Forest in 1939, for which 3 seasons' records are now available. Three 16-foot square ventilated shade frames 7 feet high admitting 3 degrees of light were constructed, and in them seed was sown and 2-year-old trees planted. These are illustrated in Plates 11A and 11B. The tops were made of ¾ by 1½-inch strips placed ½, ¼, and 1/16 of an

PLATE 11B.—Inside view of frame furnishing lightest shade (20 per cent of full overhead light), showing seedlings and instruments. Note light nature of cover similar to that found under timber.

inch apart on the 3 respective shade frames to let in different amounts of light. The ventilated sides allowed a little light to enter but no direct sunshine. Two-year-old seedlings were planted and seeds were sown in spots in the spring of 1939, and seeds were again sown both in the fall of 1939 and 1940 in each enclosure, on areas in the open, under light shade of young growth, under heavy shade of young growth, and under virgin timber. Germination, survival, and height growth of seedlings and transplants have been recorded. Light measurements were taken with Weston photometers and with black and white Livingston cup atmometers; maximum and minimum temperatures were recorded daily.

The overhead slats in the shade frames were run north and south so that the bands of sunlight would not remain in one position long enough to superheat the surface. Since the strips were 3/4 of an inch thick, a full width band of sunlight only got through for a short period in midday when the sun was most nearly overhead and due south. In the shade frame with 1/2-inch openings, streaks of direct sunlight entered only from midmorning to midafternoon; and in the frames with 1/4- and 1/16-inch openings the period was proportionally less. On the under-timber plots, light values were not always highest at noon but rather when the sun happened to find the largest opening in the crown canopy.

Photometer readings were taken at hourly intervals from 8 a. m. to 4 p. m. on several days during June, July, and August 1940. Since the capacity of the instrument would not permit pointing it straight up in

full sunlight, the readings were taken with the photometer in a fixed wire frame 1 foot above, and pointing at, a reflecting surface placed flat on the ground. The reflecting surface used was an 18-inch square piece of light grey cardboard mounted on a piece of plywood. In this manner all readings were taken from exactly the same angle and distance from the same reflecting surface. Readings in the open were considered as 100 per cent of full overhead light, and all other readings were expresssd in per cent thereof. The records obtained were fairly consistent and satisfactory; they are summarized in Table 12 along with maximum temperatures and seedling records. The maximum light readings obtained under all the shade frames were somewhat less than the ratio between openings and slats.

Black and white Livingston cup atmometers indicated the same general trend of light values as the photometers, but when used to measure small variations in low light values, the readings were too erratic for use.

Daily maximum temperatures taken during July and August 1940 did not vary greatly between the three shade frames or the weather shelter on the open plot, but maximum temperatures on the three forest-covered plots were always from 5 to 10 degrees below those taken on the open plot. This consistent difference in temperature, due to shade, is without doubt an important factor in seedling survival and growth.

In the study of seedling records the matter of cover must be considered, both ground cover and overhead forest cover. The ground cover could not be entirely removed without destroying natural seedbed conditions needed to test seedling survival and growth, both under the timber and in the open; therefore, in the beginning ground cover was left undisturbed. Later it developed that cover under virgin timber and dense young growth and under the "dense" and "medium" shade frames was not heavy enough to be a controlling or upsetting factor, and it was not found difficult to maintain the cover in a similar condition under the "light" shade frame, and light young growth, and on the open plot, by clipping the surplus vegetation. The root competition from trees on the three forest-covered plots was not controlled or compensated for, therefore its effect will be reflected in seedling behavior along with that of reduced light values.

The 2-0 planted trees on the check plot on open cut-over land showed a 68 per cent survival at the end of the third year. This is somewhat less than would be expected in an extensive plantation. On the other hand, the survival of seedlings in seed spots was 44, 87, and 30 per cent respectively for the 3-, 2-, and 1-year-olds, which is better than is usually obtained on natural reproduction plots. Both transplants and seedlings are stocky and rugged in appearance and will make good growth and survival from this date forward.

Under the "light" shade frame, survival and growth of both planted trees and seedlings were better than were obtained in the open, and in fact, the best obtained on any plot. However, these seedlings are somewhat etiolated. Their stems are slender and their foliage has an unhealthy color;

TABLE 12.—PHOTOMETER LIGHT VALUES IN PER CENT OF FULL OVERHEAD LIGHT, AVERAGE MAXIMUM TEMPERATURE, AND SEEDLING RECORDS FROM APRIL 1939 TO APRIL 1942 IN DOUGLAS-FIR SHADE REQUIREMENT STUDY

Plot description	Light values: Per cent of full overhead light			Av. daily max. temp.F. °	Douglas-fir seedling records: 1939 2-0 trees				
	Hourly average 8 a.m.-4 p.m.	Midday average	Midday maximum	July & Aug. 1940	Per cent alive April 1942	Average height (*Inches*) April 1942	1939 seedlings, per cent alive April 1942	1940 seedlings, per cent alive April 1942	1941 seedlings, per cent alive April 1942
Full exposure	100.00	100.00	100.00	85.9	68.3	10.2	44.0	87.5	30.4
"Light" shade frame	4.94	15.00	20.00	86.1	87.5	13.1	67.9	78.6	55.7
"Medium" shade frame	2.49	8.06	10.50	85.9	62.5	7.2	7.7	8.3	20.3
"Heavy" shade frame	.70	2.24	2.90	85.2	1.8	7.5	0.0	0.0	0.0
Light young-growth forest	1.65	2.73	5.40	79.2	61.5	3.2[1]	0.0	0.0	9.2
Heavy young-growth forest	.95	1.50	3.40	81.5	9.3	3.0[1]	0.0	0.0	10.3
Virgin timber	.50	.85	1.90	78.2	0.0	0.0	0.0	0.0	0.0

[1]The 2-0 Douglas-fir trees were approximately 3½ inches tall when planted. They show very little growth, or a loss, under timber because tips either died or were nipped off by rodents or birds.

if the protection of the frame were removed and they were subjected to the buffeting of wind and rain and to normal competition, they would probably not survive.

Under the "medium" shade frame, both survival and growth is below that in the open, and the remaining seedlings are definitely on the decline. While 62 per cent of the planted trees are still alive, they and the remaining seedlings have a distinctly sickly appearance and mortality is continuing. Under the "heavy" shade frame and on the plots with timber cover, only a few planted trees and 1-year seedlings remain alive, and they are rapidly succumbing. The planted trees that live just manage to burst their buds, but make no growth, while the seedlings develop long tender stems and soon crumple and die. Not all mortality occurs in the summer; some deaths were caused by "frost heaving" and some tender seedlings were killed by winter freezing.

While the foregoing records cover only a 3-year period, and were taken under controlled conditions, half of them in the complete absence of overwood competition, they do establish certain definite facts and form a starting point for further study under natural and controlled conditions. It is evident from the figures in Table 12 that reproduction of Douglas-fir has little or no chance of successful establishment in anything less than 20 per cent of full overhead light at midday, even in the complete absence of overwood competition. Seedlings did remain alive in heavier shade but they have little chance of continued survival. This in itself eliminates the possibility of securing natural regeneration of Douglas-fir under any form of continuous light individual tree selection cutting. The table further shows a rapid and proportional decline in seedling survival with the reduction of overhead light in the 3 shade frames.

Even on the sample plot classed as "light shade of young growth," located in an opening in a 30-year-old stand, where there are short intermittent periods of direct sunlight, seedlings do not remain alive beyond the second season and the 62 per cent of the planted trees that are still alive are making no appreciable height growth.

In laboratory tests with favorable soil conditions, Weaver and Clements (*35*) found a minimum light requirement of 7.6 per cent for Douglas-fir. Apparently from controlled field tests they state: "The optimum amount (of light) for many species is less than full sunshine. The seedlings of Douglas fir thrive best at about 50 per cent of full sunshine."

The foregoing records taken under seed trees, under partial cover of an old-growth stand, under full cover of young growth and virgin forest, and also under controlled shade without forest competition, indicate certain definite things:

1. Douglas-fir seedlings on a good seed bed will become established and grow under light shade, but as the shade increases they show proportionally less thrift.

2. Root competition from overwood trees is perhaps second only to light among the factors militating against Douglas-fir seedling establishment.

3. Seedlings in shade frames and in the absence of root competition from an overwood are making good growth in a maximum of 20 per cent of full overhead light, but the field studies indicate roughly that at least half of full overhead light is necessary for seedling survival and reasonable growth.

4. Satisfactory Douglas-fir restocking has been observed in openings of approximately an acre in size or larger (Plates 9 and 10) but with decrease in size of openings the regeneration runs progressively heavier to hemlock and the other tolerant species, or to brush where the site is unfavorable for the tolerant species.

From these studies and findings, covered earlier in this report, it is evident that Douglas-fir natural reproduction cannot be obtained under shade conditions that would follow continued light individual tree selection cutting—instead more tolerant competitors would probably come in. If Douglas-fir regeneration is desired, the removal in the first cut or later will have to be heavy, probably over 50 per cent, or be groupwise with openings an acre or larger in size.

SPECIES COMPOSITION IN NATURAL REGENERATION

Generally speaking, the species best suited to the site and best able to compete with its associates will ultimately predominate in natural regeneration following clear cutting or following crown fires, considering the region as a whole. On individual areas there are several factors that may affect the species composition of the new forest. Ground conditions are changed by logging and burning, and land that produced a mixed stand of Douglas-fir and more tolerant conifers, hemlock, cedar, and balsam firs, may after cutting regenerate to a stand largely of Douglas-fir. Such land, where at first only Douglas-fir seedlings can become established, is likely to become more favorable for the more tolerant species once a new cover is established (Plate 1). Thus, the stand in time may revert to the climax type of tolerant conifers (*30*). The usual preponderance of Douglas-firs following the cutting of a mixed stand is partly due to the much higher rate of mortality of hemlock seedlings on exposed areas, so that even where hemlock seed trees predominate, Douglas-fir seedlings are likely to be in the majority, or on severe sites to be the only species to become established. Where several species all succeed reasonably well, the composition of the reproduction is more or less due to the coincidence of the seed crop of the various species with favorable seasonal weather.

The incidence of seed crops is a very important factor in determining species composition where all species survive fairly well. If there is an abundant seed supply of one species immediately following a slash fire, that species is likely to predominate. This is borne out by reproduction plot records and further substantiated by the stand composition on permanent growth plots in young stands. A cut-over portion of the Wind River Valley (near Carson, Washington) that has reforested gradually over a period of years, during which time there have been abundant seed crops of all the original species, now supports a stand of regeneration that consists of about 80 per cent Douglas-fir and the remaining 20 per cent divided between western red cedar, western hemlock, western white pine, and balsam firs (Plate 12). The composition of the original forest was quite similar. This similarity of old and new stands is found on many areas in the region. On the other hand, when a forest near Quinault, Washington, that ran heavily to spruce and cedar, was cut and slash burned in 1928, heavy seed crops of hemlock followed and as a result hemlock predominates in the new stand.

Some actual figures on change in species composition are shown in reproduction counts that were made on sample plots that reburned and later restocked. One area near Kapowsin, Washington, cut and slash burned in 1925, had an average of 240 Douglas-fir and 1,520 hemlock seedlings per acre when it reburned in 1930; some good Douglas-fir seed crops followed, and by the end of 1933 the area had a stand of 960 Douglas-firs and 720 hemlocks per acre. Another area near National, Washington, was cut and burned early in 1925 and by the end of 1926 when it reburned it had a stand of 2,560 hemlock and 160 cedar seedlings

PLATE 12.—Natural reproduction on cut-over land 500 feet from the edge of virgin timber 17 years after logging and slash burning. It is on a gentle northeast-facing slope near the study plots in the Wind River Valley listed in Table 15. Like the original forest the reproduction consists mostly of Douglas-fir with a light mixture of western white pine, hemlock and silver fir.

per acre and no Douglas-fir. The second fire produced slightly more severe site conditions and some more favorable Douglas-fir seed years followed, and by the end of 1936 the area had an average of 800 Douglas-fir and 1,120 hemlock seedlings per acre and no cedar.

The Panther Creek division of the Wind River Experimental Forest now supports a practically pure stand of 100-year-old Douglas-fir, yet surrounding old-growth forests contain a moderate mixture of hemlock, cedar, white pine, and balsam firs, and there are cedar snags from the old original forest scattered throughout the area. A comparable situation exists at the Cascade Head Experimental Forest where there are scattered Douglas-fir and cedar snags in an almost pure 90-year-old stand of hemlock and spruce. Ecological conditions as well as seed crops no doubt affected composition of these two stands.

The sample plot area at Wilark, Oregon was cut and burned in 1924 and 1925, was reburned in 1929, and again in 1932. The only seed supply available was the receding edge of Douglas-fir timber that was approximately a mile away when the first burn occurred. After each of these burns the only regeneration that appeared was a very light stand of Douglas-fir, although there was considerable hemlock and cedar in the original stand.

Frequently stands having scattered large old Douglas-firs over an understory of spruce, hemlock, or balsam firs, are selectively logged and all Douglas-firs removed. There being no Douglas-fir seed source on such areas, the regeneration that does come in is certain to be of other species, even if the openings are large enough to permit the survival of Douglas-fir. Individual tree or group selection in a mixed forest with established regeneration of tolerant species is certain to favor the tolerant species.

Thus, on areas that can produce several species, the species that will predominate in the regeneration will be determined by variation in seed crop, complete absence of seed of some species or by conditions favoring seedling survival of one species over another because of shade, moisture conditions, reoccurring fires, or some other cause.

RELATION OF GRAZING TO DOUGLAS-FIR REGENERATION

The grazing of cattle and sheep on logged-off lands of this region has been practiced to some extent for many years (*14*); though latterly the practice is spreading, only a very small percentage of the Douglas-fir cut-overs have ever been grazed by domestic livestock. The financial returns to the stockman-owner have been variable, sometimes profitable, often not. The effect upon the land and upon reforestation is also variable, and is not easily appraised. But because the practice of grazing on these lands is increasing at the moment, it is important to know the effect of this practice on reforestation where management for trees is the ultimate goal and where timber production is the highest use.

This discussion is not concerned with lands of good soil on gentle topography which can be converted from stump land to grassland without danger of erosion or of reversion to brush and which will serve permanently their highest use as pastures. It is only considering lands which are temporarily to be used for grazing, and upon which reforestation for timber production is desired.

Grazing practice at the present time falls in two categories—first, artificially supplementing the pasturage by sowing grass seed on freshly logged and burned land (or merely burned land) by airplane or by hand, and second, using the natural pasturage of browse and weeds that follow logging and burning without any treatment. The first category is necessary for cattle range, but sheep do well without grass sowing. Goat grazing is uncommon in this region except on land being cleared for agricultural use, and goats, like sheep, thrive on browse, and if sufficiently concentrated can be very destructive to woody growth, both shrubs and trees.

Specific data are scant as to the effect of grass sowing, and subsequent grazing, upon Douglas-fir regeneration. Observational study indicates that this practice is discouraging to tree reproduction, but does not necessarily preclude seedlings. Much depends upon the density of the sod cover and the intensity of use. There is no doubt that a heavy sod is detrimental to Douglas-fir establishment and the trampling of animals where the forage is heavy does great injury to young trees. On the other hand, the lessening of the fire hazard, which is one of the asserted advantages of grazing of stump lands, may give the young trees that do survive sod competition and the hoofs of the stock a better chance to reach maturity; if the brush is kept in check by sod and livestock, that may still further help the tree seedlings. However, there are certain economic and social factors that militate against forest regeneration on grass-sown lands. This practice usually presupposes year-long residence by the owner of stock and land. If he makes an investment in grass sowing, fencing and building, he is naturally anxious to get his investment back by as many years of grazing as possible, and may resent the invasion of unpalatable "brush"—with which is mixed tree reproduction and in which category young trees are sometimes unfortunately placed. This may result

in practices, aimed to prolong grazing use, which are inimical to the re-establishment of a full forest stand.

In southwestern Oregon in recent years considerable forest land, much of it brush covered, has been classified as suitable for grazing and has been intentionally burned, seeded with grass, and grazed, mostly by sheep. There is no expectation that such land will restock with trees, though some will filter in with the brush unless the land is reburned or repeatedly slashed.

The practice of livestock grazing—particularly sheep grazing—on newly logged lands without grass sowing has been advocated by some foresters for years for several reasons—it requires no investment for fencing, sowing, etc., it brings to the owner a small income while the land is in the unremunerative reforesting stage, it does not necessitate year-long residence but can be practiced with transient sheep, it may lessen the fire hazard, and, if the animals are properly handled, favorable cover conditions can be obtained to give the tree seedlings a start. The native plants, such as fireweed, peavine, and huckleberry, may furnish forage in diminishing amounts for a period of approximately 10 years from the time of cutting until the establishment of a new forest. The ability to obtain proper handling appears to be the key to the situation. Proper handling implies uniform utilization, i.e., grazing which is not heavy enough to encourage livestock to browse seedlings and which is allowed only when seedlings are not likely to be seriously injured by trampling.

Some intensive study has been made both to learn the effects of unsown Douglas-fir stump-land pasturage on sheep and the effect of sheep on the vegetation, particularly tree reproduction. Observations made through a term of years on cut-over land in the Wind River Valley, Washington, beginning 5 years after logging and slash burning, gave informative results. This study, made on level ground, showed better Douglas-fir seedling establishment within fenced enclosures than on the grazed area outside during the first few years of grazing use, but during later years when vegetation inside the enclosures became excessively heavy, seedling establishment was better on the grazed area outside. Grazing damage to reproduction in the form of cropping and trampling was noted on parts of the area where the sheep were bedded or otherwise concentrated, but not elsewhere. Vegetation that was palatable to the sheep, mostly fireweed, made up half of the total cover when grazing started; it diminished by one-half in the first 2 years of grazing use.[21] In the same period and immediately following there was a marked increase of bracken, which is not eaten by sheep. By the second year of grazing and the seventh year after logging, palatable plants began to disappear, and by the end of an additional 7 years there was very little forage value left on the area, except in one small swale where the soil was deeper and moister than elsewhere, and a fairly heavy sod became established.

This preliminary study of a single, but representative, area of the Cascade region indicates that considerable grazing use can be obtained on cut-over lands without damage to regeneration between the time of

[21]Reid, E. H., Isaac, L. A., and Pickford, G. D. Plant succession on a cut-over, burned, and grazed Douglas fir area. Pac. N. W. For. and Range Expt. Sta., Forest Research Notes No. 26. March 26, 1938. (Mimeo.)

logging and the establishment of a new forest, provided proper handling of the livestock is obtained—grazing lightly or not at all while seedlings are young and tender, and preventing heavy or overgrazing. Such use will not delay natural reforestation; it may lower the fire hazard, temporarily at least, by the consumption of material that would make flashy fuels; it probably will alter gradually the natural plant succession and in some localities encourage bracken. Whether it is economically practicable will depend on prevailing markets, and local conditions. It is bound to be temporary, 10 years on the average, if natural reforestation is desired and attained. Because of variation in cover composition some areas may offer better and longer grazing use and others less.

Cut-over, and now forested, foothills of this region are dotted with deserted homesteads where families have tried without success to live under a grazing economy. These lands have now become for the most part neither farms nor forests but "brush patches." To prevent a repetition of this social tragedy, extreme care should be exercised to determine which lands are suitable for permanent grazing use ordinarily with artificial grass seeding and which are suitable for forest use but offer temporary grazing from native vegetation. Once grazing starts on lands chiefly valuable for forest purposes, a danger lies in trying to maintain such use at the expense of forest regeneration by reburning, overgrazing, or slashing. This has in the past often resulted in bracken and brush fields that have neither forest nor forage value and are difficult to protect against fire.

GROWTH OF SEEDLINGS AFTER ESTABLISHMENT

Seedlings can be considered to be established after they have survived the factors which are particularly fatal to them during their first few years. Thereafter they are still subject to death from many causes, but at a diminishing rate. Their survival is predicated upon the rapidity with which their tops get above competing vegetation, their roots penetrate to the deeper soil layers, and their stems become too large for injury by certain enemies of very small seedlings. The more quickly a seedling gets its head above competing vegetation and keeps it there, the more likely it is to survive.

Height Growth of Seedlings

The first season Douglas-fir seedlings become only an inch or two tall (on average wild land); the second year they grow no more than the first, on the average; but after their third growing season they lengthen out decidedly, and by the sixth year the superior trees will be growing more than a foot a year.

Growth varies greatly with differences of site, soil, exposure, and cover. As an instance of height growth on one site III area, and as showing comparatively the effect of a light weed shade on a fresh burn in contrast to a moderately heavy brush cover on a 5-year-old burn, the heights of the 1928 seedlings on the Wind River study plots are given for their first 9 years in Table 13. For the open area and the brushy area are given separately the average height of all seedlings and the average height of the tallest 25 per cent.

TABLE 13.—Average Total Height of the 1928 Crop of Seedlings from the End of the First to the Ninth Growing Season After Germinating on the "Open" Area and on the "Brushy" Area

	1928	1930	1932	1934	1936
	Inches	Inches	Inches	Inches	Inches
	Fresh burn—light weed shade				
Average height of all seedlings	1.5	3.2	7.9	17.0	28.8
Average height of tallest 25 per cent	2.0	5.3	15.8	32.6	55.9
	5-year-old burn—moderately heavy brush cover				
Average height of all seedlings	1.7	2.5	4.6	8.7	12.0
Average height of tallest 25 per cent	2.3	4.2	8.2	16.7	24.5

It will be noted that the growth on the open area is double that on the brushy area after the first few years. This is probably due to less competition and to the higher soil moisture content at the 6- and 12-inch depths on the open area, as shown by soil moisture records. The fact that initial mortality was higher on the open area may have resulted in natural selection for survival of only vigorous specimens that subsequently grew better than seedlings that had not been subjected to such severe selection.

Rodent-cropping often retards seedling height growth, and while this pruning might not be fatal in itself it may handicap the seedling in its competition with brush, fern, and weeds. On one area in a fern patch in the Oregon coastal region (Cascade Head Experimental Forest) where there had been heavy rabbit and mountain beaver cropping, the average net height growth of the seedlings was less than a foot in 8 years. Ordinarily on this site 8-year-old trees should be 4 to 5 feet in height.

Table 14 by McArdle and Meyer (*24*) shows for sites I to V the number of years dominant Douglas-fir seedlings require to grow from 1 to 5 feet in height.

TABLE 14.—PERIOD REQUIRED BY DOMINANT DOUGLAS-FIR SEEDLINGS TO GROW TO VARIOUS HEIGHTS FOR EACH SITE CLASS

Height above ground (feet)	Growing period required, by site classes				
	I	II	III	IV	V
	Years	Years	Years	Years	Years
1	3	3	3	4	5
2	4	5	6	6	7
3	5	6	7	8	9
4	6	7	8	9	10
5	7	8	9	10	11

It is the dominant seedlings that comprise the ultimate stand, and they give perhaps the best index of the time it takes young trees to overtop their weed and brush competitors for light. On a plantation with 4 x 4 spacing, seedlings began overtopping vegetation and closing crowns by the fifth year, and by the tenth year had completely crowded out all competing vegetation as shown in Plate 8.

CASE HISTORIES OF RESTOCKING UNDER VARIOUS SITE CONDITIONS

Because of the wide variance in site conditions, fire history, and seed supply, there is an equally wide difference in the rate at which logged-off land in the Douglas-fir region is reforesting. This is demonstrated by the records of germination and survival of seedlings on 32 groups of "semipermanent" sample plots,[22] located on 20 areas in widely scattered parts of the region (Figure 1). Most of these plots were examined one or more times yearly from 1926 to 1936. Certain of these groups can be subdivided to demonstrate contrasting conditions, such as burned versus unburned surfaces, and differences in exposures or in distance from source of seed.

Ten of these groups (31 per cent) were fully stocked when last examined; 3 of the groups (9 per cent) had light or medium stocking; 7 of the groups (22 per cent) were well stocked in spots, but on the remainder of the area had few or no seedlings; 5 of the groups (16 per cent) were well stocked adjacent to timber, but seedlings diminished with the increase in distance; and 7 of the groups (22 per cent) were nonstocked. Unfavorable site conditions or lack of seed often resulted in medium or light stocking, but the irregular and nonstocking usually resulted from reburns or from too great a distance from a seed source. Several of these groups of sample plots will be used as case histories to illustrate how certain factors affect the rate of restocking.

Effect of Exposure and Distance from an Adequate Seed Supply on Restocking

The restocking on different exposures and at varying distances from a source of seed are treated jointly because data for both conditions happen to be obtained from the same case studies whose sample plots were spaced at regular intervals from green timber on two or more different exposures. As shown in an earlier section of this circular, south exposures are most severe and north exposures least severe from the standpoint of seedling survival; the east and west exposures and flat surfaces lie somewhere between. Naturally, the more gentle the slope the less the influence of exposure manifests itself.

Wind River Area.—The group of sample plots on different exposures and at varying distances from virgin timber with the longest (22 years) and most complete record is on the Columbia National Forest near Carson, Washington (Wind River Permanent Sample Plot 85). Here in 1918 two lines of sample plots were laid out across land logged and slash burned

[22]The "semipermanent" sample plots under observation in this study were in groups of 20 or less, and because of this small number of plots in a locality and the small size of plots the stocked-quadrat method of measuring restocking was not readily applicable. The author has, therefore, set up the following scale to denote restocking based on well distributed seedlings: Nonstocking—100 or less per acre; light stocking—101 to 400; medium stocking—401 to 700; full stocking—over 700.

just previously that year. They extend across the Wind River Valley from uncut virgin timber on one side to uncut virgin timber on the other, going down a gentle northeast exposure for a half mile, across the river bottom lands for a quarter of a mile and up a rather steep southwest exposure for another quarter of a mile.

TABLE 15.—SEEDLING ESTABLISHMENT ON A CROSS SECTION OF THE WIND RIVER VALLEY DURING THE 22 YEARS THAT HAVE ELAPSED SINCE IT WAS LOGGED AND SLASH BURNED IN 1918

	Distance from uncut timber (Chains)		Number of seedlings per acre 5th year 1923	10th year 1928	15th year 1933	22nd year 1940
Distance from green timber to the southwest	2	Gentle northeast exposure	2,720	6,000	8,240	7,120
	4		3,320	5,840	6,240	5,400
	6		1,760	2,880	3,640	3,840
	8		1,493	3,039	3,413	3,518
	10		1,040	1,680	2,240	1,920
	12		400	1,040	1,280	1,280
	14		480	1,360	2,000	1,680
	16		320	1,120	1,360	1,440
	18		400	800	720	800
	20		480	880	1,120	1,040
	22		......	320	400	560
	24		160	320	480	640
	26		160	240	480	720
	28		320	960	1,280	1,760
	30		160	240	320	800
	32		160	240	320	560
	34		......	320	320	1,280
	36		160	320	480	480
	38		160	160	480	480
	40		......	480	320	960
	42		160	480	480	800
	44		320	320	320	480
	46		320	320	320	640
Distance from green timber to the northeast	40	River bottom lands	480	160	320	160
	38		......	......	......	......
	36		......	......	......	......
	34		640	800	320	320
	32		80	80	80	80
	30		160	160	160	......
	28		......	......	......	......
	26		......	......	......	......
	24		160	320	320	400
	22		160	160	320	480
	20	Steep southwest exposure	......	......	......	......
	18		480	320	160	640
	16		......	......	......	......
	14		160	160	320	320
	12		......	160	160	160
	10		160	320	320	480
	8		640	480	480	——
	6		240	320	400	480
	4		320	80	80	240
	1		3,520	3,680	3,520	4,480

The stocking per acre on different exposures at distances up to half a mile from virgin timber 5, 10, 15, and 22 years after logging are shown in Table 15. Douglas-fir constitutes about 80 per cent of the seedlings on this area.

The gentle northeast exposure was, by the end of the fifth year, fully stocked for an eighth of a mile and medium stocked for a quarter of a mile out from the timber's edge; by the tenth year it was fully stocked to the quarter-mile point and lightly stocked from there to the half-mile point; by the close of the fifteenth year the area between the quarter- and half-mile points had restocked to the medium grade; and by the end of the twenty-second year the area was fully stocked to the half-mile point from the edge of the timber. This area is shown in Plate 12.

On this rather favorable exposure, yet in a locality of severe summer climate, a quarter of a mile from the abundant seed source is the limit to which adequate regeneration took place within 10 years after logging. Although it took 10 years to fully restock, it must be remembered that 10 years of growth have not been lost on such an area because the 200 dominant trees that will make the ultimate forest probably started during the first few years; the fillers that come in later and aid natural pruning will fall out before maturity or will be harvested as thinnings. Between the quarter- and the half-mile points the regeneration "filtered in," increasing gradually from season to season until it had reached medium stocking in the fifteenth, and full stocking in the twenty-second year after the slash fire.

Throughout the 22-year period on this northeast exposure, the abundance of new seedlings from year to year was proportional to the abundance of the seed crop during the previous year. The development of brush and herbaceous cover here was not rapid or heavy, and even in the twenty-second year after logging there were spots on the area where the density of the vegetative cover was not more than 50 per cent. Cover development is much heavier in some parts of the region than on this area.

On the southwest exposure and river flat the rate of restocking was an entirely different story from that of the more favored northeast exposure. Within the first 5 years this area became fully stocked for only a couple of hundred feet from the edge of the uncut timber and was lightly or nonstocked from that point out a quarter of a mile to the foot of the slope and for an additional quarter of a mile across the bottom lands. During ensuing years, seedlings increased in some spots and were choked out in others until at the end of the 22-year period the restocking beyond the 1-chain point was about as light and no better than it was at the end of the fifth year, i.e., in the neighborhood of 250 per acre and very irregular.

There are four factors that would help to account for the variation in restocking on this area—prevailing winds, seed fall, cover, and exposure; the last is by far the most important.

Elbe, Washington, Area.—Another case that illustrates the influence of exposure and distance from seed source on the rate of restocking is the group of plots near Elbe, Washington in the northern Cascades. The area was cut and burned in 1925, the plots laid out in 1926 and examined

yearly until 1936. Starting about 400 feet below a bank of green timber, the plots were placed at approximate 200-foot intervals on a moderately steep north-facing slope for 800 feet, up a similar south exposure and across a flat hilltop for an equal distance, then down another north exposure. At the plot nearest the timber there were 800 Douglas-firs and 3,200 hemlock and other seedlings per acre; at the foot of the north slope (1,200 feet from the green timber) 800 Douglas-fir and 960 other seedlings; from this point on, up the south exposure and across the flat hilltop, an average of only 53 Douglas-fir and 187 other seedlings per acre were found, quite evenly distributed over the area. But the second north exposure, beyond the flat hilltop and most distant from a seed source, had 640 Douglas-fir and 480 other seedlings to the acre. Like the Wind River tract, this area showed that the amount of reproduction diminished as the distance from green timber increased on a given exposure, and also that restocking on north exposures was very much better than elsewhere.

Knappa, Oregon, Area.—This case in the coastal "fog belt" region shows the rate of restocking on a north and a south exposure at varying distances from the seed source. The original stand contained considerable spruce and hemlock, and after logging the herbaceous and shrubby cover was heavier than in most parts of the region away from the "fog belt" and on these plots averaged over 80 per cent density after the second year. A line of plots at 100-foot intervals extended from the virgin timber down a moderate slope on a northerly exposure for a distance of a quarter of a mile, then on for an additional quarter of a mile up a gentle southerly exposure. The plots were established in 1926 and examined annually until 1936. By the end of the second year, the entire northerly exposure was well stocked with seedlings, and they continued to filter in until by the tenth year there were 400 Douglas-firs and over 2,000 hemlock and other seedlings per acre. Stocking decreased as the distance from the timber increased, but was still adequate at the quarter-mile point.

On the southerly exposure there were only 220 widely scattered seedlings to the acre by the end of the second year; their distribution was patchwise and bore no direct relation to the distance from the seed source. Germination on this south exposure was light after the second year, and was exceeded by mortality, so that by the tenth year the stand was reduced to 160 seedlings per acre—virtually nonstocked. It is evident that both the increased distance from the seed source and the more severe site conditions were the factors that prevented this south exposure from restocking.

Brinnon, Washington, Area.—This area on the east side of the Olympic Peninsula demonstrates in a striking manner the difference in rate of restocking on the north and south exposures in a narrow V-shaped canyon. This narrow valley was logged about two-thirds of the way up the slope, or approximately 2,000 feet up from the bottom on both sides of the creek, leaving an ample seed supply on the slopes above. The cut-over area was burned in 1925, and the plots laid out in 1926. By the close of the 1929 season, the south exposure had an average stocking of 80 Douglas-fir and 320 hemlock and other seedlings to the acre, while the north exposure had 373 Douglas-fir and 5,663 hemlock and other seedlings to the acre.

Just over the ridge to the south of this heavily stocked north exposure where the timber was cut and the slash burned at the same time, as in the V-shaped canyon, a south-facing slope with virgin timber above had in the same period only 40 Douglas-fir and 240 hemlock and other seedlings to the acre.

Ryderwood, Washington, Area.—A measure of restocking out from virgin timber on a moderate west exposure was obtained on this clear-cut area which was slash burned in the spring of 1925. By the close of 1928 there were approximately 250 seedlings to the acre in the zone within 300 feet of the timber's edge. In 1930 there was a good seed crop, and the following year the stocking increased to approximately 650 to the acre in the zone within 600 feet of the timber's edge.

Medium seed crops occurred from 1930 to 1935, and the reproduction close to the timber increased in density, but the zone of restocking did not extend beyond 600 feet from the edge of timber. Adverse winds and heavy cover prevailed which, along with the severe exposure, account for the lack of restocking beyond the 600-foot point. An older cutting on somewhat rolling topography to the east of this same block of timber is now adequately restocked for a long distance out from the timber's edge.

Tillamook Burn Area.—Observations of regeneration on parts of the great Tillamook burn[23] substantiate the findings on the groups of "semipermanent" plots discussed in preceding paragraphs. An area having both north and south exposures was logged and slash burned about 1930. In 1933 the Tillamook fire reburned the area to the edge of the virgin timber, killing all regeneration and scattered old trees. Other than the block of timber there was no seed source for miles, and since the area was slash burned and then reburned 3 years later, subsequent reproduction was practically certain to have come from seed cast by the adjoining timber. Two years after the second fire, the area was found to be fully stocked for the first 525 feet from the timber, and partially stocked for an additional 525 feet, and sparsely stocked or nonstocked for the remainder of the mile strip traversed. A medium or heavy seed crop of all species had occurred in at least 1 of the 2 years preceding the examination.

On the restocked portion of this strip the seedlings were grouped according to exposure; 1,395 seedlings per acre were found on the moderate or steep northerly exposures as compared with 870 seedlings per acre on comparable southerly exposures. Similar relationships were found in the examination of the rest of the burn (most of which was through virgin timber), both in regard to distance from source of seed and in regard to number of seedlings on northerly and southerly exposures.

These six case studies illustrate conditions that may be found on cut-over land throughout the region, both outside and inside the national forests. They show the wide variation in the distance from the timber's edge to which adequate restocking took place. Roughly the restocking falls within the limits of seeding distances shown by the dissemination

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[23]See footnote 10.

tests cited in an earlier section. It varied from 200 feet on a severe southwest exposure to over half a mile on a gentle northeast exposure. In every instance, the density of restocking on northerly exposures was inversely proportional to the distance from the timber's edge, but on the southerly exposures the restocking was erratic and noticeably poorer than on north exposures, or lacking. This demonstrates that if adequate restocking is to be obtained on southerly exposures or other severe sites special provision will have to be made, such as a more adequate seed supply, less or lighter slash burning, and more shade.

Effect of Slash Burning on Restocking

Douglas-fir is a sun-loving tree and it is a well established fact that excellent stands of this species followed presettlement forest fires. However, it was not the fire, but the opening up of the ground to full light that made possible the new growth. Though reproduction also follows clear cutting and slash burning, when conditions of seed supply and site are favorable, it appears that the burning is not necessary for regeneration. Earlier in this report it has been stated that in most instances slash burning is desirable only as a fire protection measure, not as a means of promoting regeneration, and that Douglas-fir reproduction will come in on either burned or unburned cut-over areas. A series of 7 of the groups of semipermanent plots affords a good index of the rate of restocking on burned and unburned surfaces (Table 16), for in each group some of the plots were on burned surfaces and some on unburned surfaces. Three of these groups of plots were near Westfir, Oregon on one logging area, but established a few years apart; the others were farther north in Oregon and Washington.

This table shows the amount of reproduction (90 per cent of which was Douglas-fir) from 6 to 10 years after logging on burned and unburned plots, where other conditions were comparable. Five out of the 7 areas (numbers 1, 2, 3, 4, and 7) have better stocking on the unburned surfaces, all classed either as medium or full stocking, while on the burned

TABLE 16.—NATURAL REGENERATION ON BURNED AND UNBURNED SURFACES OF 7 AREAS 6 TO 10 YEARS AFTER LOGGING

Area	Seedlings per Acre		Remarks
	Burned surface	Unburned surface	
1. Wilark, Oregon	62	1,280	Seedlings on unburned came in immediately.
2. Ostrander, Washington	80	320	Heavy vegetative competition.
3. Westfir, Ore., Area A	160	512	Seed crop before burn but supply limited.
4. " " " B	64	1,760	Heavy seed crop before burn, none after.
5. " " " C	820	240	Heavy seed crop after burn, none before.
6. Carson, Washington	6,200	4,720	Light competition and ample seed.
7. Shelton, Washington	2,129	10,720	Gravel soil and ample seed.

surfaces 3 of these areas are nonstocked, 1 lightly stocked, and 1 fully stocked. On all 5 there was a good seed crop, while logging was in progress or just before, and poor seed crops during the first year or two following the slash fire.

On the two areas where heavier restocking occurred on the burned surfaces (number 5 and 6), there were poor seed crops while cutting was in progress, or just prior thereto, but good seed years immediately after the slash fire.

The three Westfir groups of plots offer illuminating demonstration of the effect of burning on regeneration. Area 3 (Table 16) was cut late in 1923 and partially burned in the spring of 1924. The seed crop of 1923 was very heavy, but during the succeeding 2 years was a failure or very light. This was a severe site; there was considerable mortality and few new seedlings became established after the first year, so the stocking after 10 years was only 160 and 512 seedlings per acre on the burned and unburned surfaces respectively.

Area 4 plots were established in 1927 5 miles up the canyon from area 3. A good seed crop was borne in 1927, none in 1928 and 1929. The area was burned in the fall of 1927 and again the next spring, thereby effectually annihilating the seed and seedlings on the burned surfaces. In spite of a good seed crop in 1930, few seedlings resulted from it on either burned or unburned surfaces, probably because of the vegetative competition which had by then developed. By 1936 the burned surfaces had only 64 seedlings per acre, while the unburned surfaces (where the 1927 seed survived) had a stand of 1,760 seedlings per acre.

Area 5 (2 miles up the canyon from area 4) was cut in 1928 and 1929, burned in 1929, partly reburned in 1930, and plots established then on burned and unburned surfaces. The first seed of consequence fell on this area in 1930, and in 1931 conditions for establishment were good on the burned surfaces, but on the unburned surfaces they were unfavorable because of heavy debris and competing vegetation. As a result, in 1936 the burned surface had 820 seedlings per acre, the unburned 240. Thus, areas 4 and 5 illustrate completely opposite results on burned and unburned surfaces because of the timing of seed crops in relation to conditions for germination and survival. Plate 13, A and B, illustrates conditions on one area in western Washington 8 years after cutting, half of which was burned and half left unburned.

A temporary plot survey[24] made in 1925 on 13 widely scattered tracts that had been logged within the previous 3 years showed from 4 to 24 times as many seedlings on unburned spots as on burned surfaces. Very little seed was produced in 1922 and 1924, but there was an exceptionally heavy crop in 1923. Most of the seedlings on the unburned surfaces evidently sprang from 1923 seed, while on the burned surfaces this seed was destroyed by the slash fire and none subsequently fell.

[24]Isaac, Leo A. A survey of natural reproduction on cut-over lands in the Douglas fir region of Oregon. Pac. N. W. For. and Range Expt. Station. April 1926. Unpublished report.

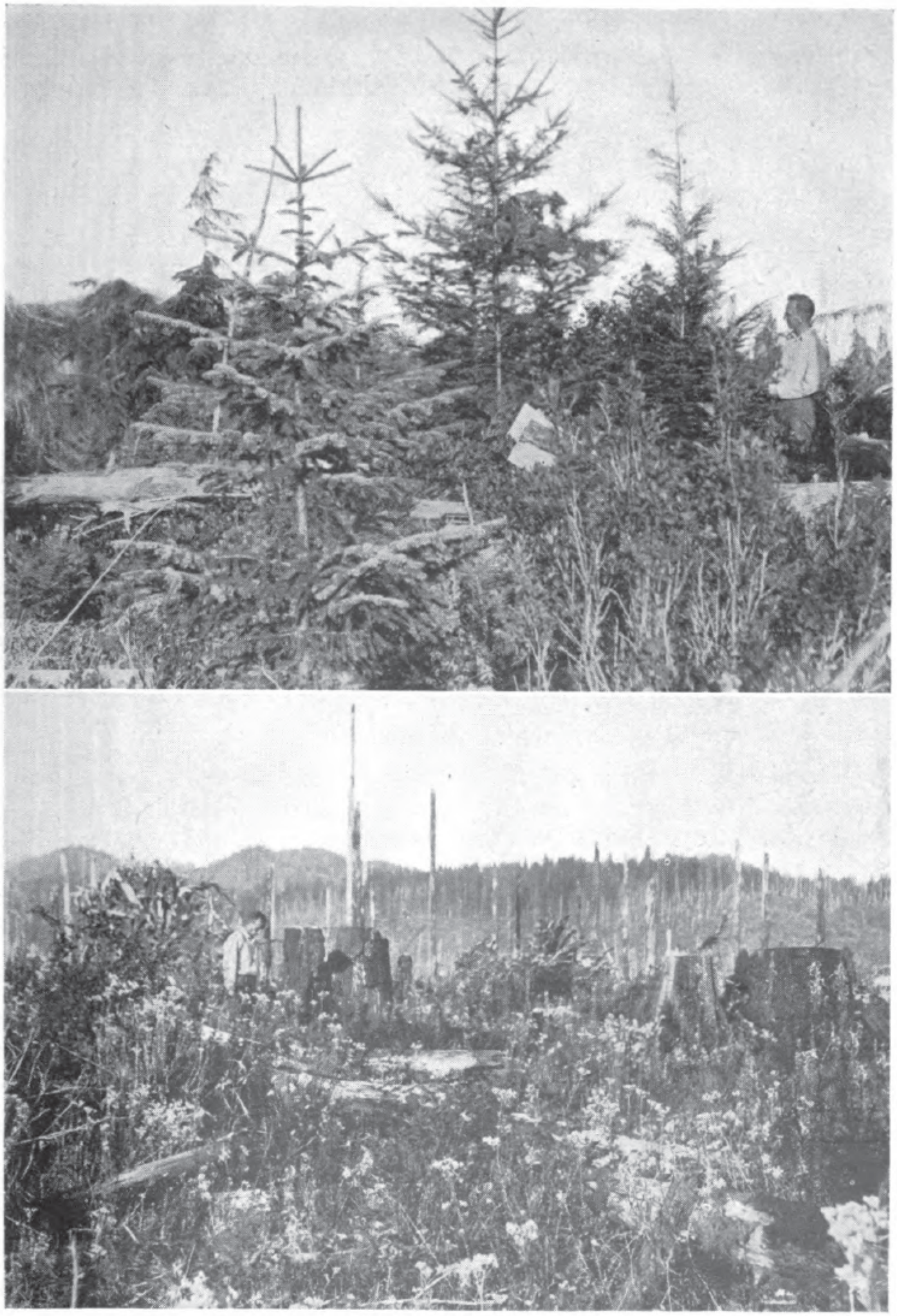

PLATE 13.—A clear-cut area near Humptulips, Washington, 8 years after cutting. A.—Unburned, with abundant good-sized saplings, the hemlocks having started as advance reproduction in the virgin forest, the Douglas-fir and Sitka spruce reproduction starting subsequent to logging. B.—Slash burned 1 year after logging, with but a sparse stand of small seedlings growing in a heavy cover of fireweed, pearl everlasting, bracken, etc.

A total of 118 cut-over areas in the region were examined in the course of a study of slash disposal (*31*); 41 of these areas were unburned, the rest burned. The age of cutting varied from 2 to 30 years and the analysis shows

> ". . . that the unburned areas were consistently better stocked (than burned areas). Seven years after cutting they averaged 50 per cent (stocking) against 25 per cent for the burned areas. . . . It is significant that in the first two decades after logging, as a general principle, unburned areas attain a certain degree of stocking from 3 to 5 years quicker than burned areas. These data represent average conditions and may be relied upon as a general indication of results to be expected; but many instances could nevertheless be cited in which slash-burned areas have reforested satisfactorily immediately after burning."

The foregoing records indicate that in general—but not universally—restocking is not only heavier, but more prompt on unburned than on burned surfaces. Success or failure under either condition depends on two variables: First, whether or not there is seed on the ground when logging is completed; and second, whether seedling establishment conditions are best on the burned or unburned surfaces (and it can be either) when there is a seed fall following the slash fire.

Effect of Reburning on Seedling Establishment

The preceding discussion of the histories of "semipermanent" plots shows that restocking may be, and often is, reduced and delayed by slash burning. A second fire all too frequently occurs on the cut-overs and further retards restocking. Nineteen of the 32 groups of plots, or 60 per cent, were visited by a second slash fire within the 10-year period and were partially or wholly reburned, and at least 2 areas were visited by a third fire. Fourteen out of these 19 areas are now classed as nonstocked or stocked only in spots. This is inevitable, (a) because each successive fire destroys most or all of the existing reproduction, (b) because the seed source is constantly diminishing on most areas, as the seed trees that by chance escaped the first fire die, blow down, or are killed by the second fire, and (c) because with each successive year the edge of the uncut timber is usually receding (Plate 14, A and B).

The first area listed in Table 16 (Wilark, Oregon) has an interesting history. Here the virgin stand produced a heavy Douglas-fir seed crop in 1923; late that year and early in 1924 it was cut. A good stand of reproduction promptly developed from the 1923 seed crop. Early in the spring of 1925 the slash was burned except for a patch of about 30 acres in the center of the area where the slash was not heavy. Except on the unburned patch, all seedlings were killed by the 1925 slash burn. By that time, there were no more green trees within seeding distance, and the burned surface lay practically barren of reproduction. In the spring of 1929, most of the burned surface, then covered with highly inflammable

PLATE 14.—An area near Heisson, Washington, clear-cut 9 years before with scattered seed trees and virgin timber in the immediate vicinity. A.—Slash burned lightly but once, excellent Douglas-fir reproduction. B.—The area on the left half of the picture was run over by a second fire 5 years after logging, and has no visible natural reproduction; the area to the right of the center of the picture has had but the single slash burn and is well stocked with seedlings.

dry bracken and fireweed, caught fire and reburned. Again in 1932 the area reburned, and strangely enough the original unburned spot (that now supported a good stand of regeneration—Plate 7) escaped the third fire. Fifteen years after cutting (1938) the unburned spot supported a stand of 1,280 seedlings per acre (mostly from the 1923 seed crop) and the burned surface supported a stand of 62 seedlings per acre.

Where there is a constant seed supply and site conditions are not too unfavorable for seedling establishment, areas will restock even after repeated burns. There are two notable examples of this sort among the groups of sample plots.

A cut-over area near Kapowsin, Washington, within 1,000 feet of standing timber, was slash burned in 1925, became restocked at once satisfactorily, was reburned in 1931 and all reproduction killed, but by 1933 had 1,680 Douglas-firs and hemlocks per acre. Another area near Elbe, Washington, cut and burned in 1925, became restocked at once with nearly 3,000 hemlocks and cedars to the acre (north exposure); it reburned in the fall of 1926, with the loss of all reproduction, but by 1936 had nearly 2,000 seedlings to the acre.

Unfortunately, such instances of restocking after repeated burns constitute the exception, not the rule, and occur only where there is an ample permanent seed source and conditions for seedling establishment are favorable. On most areas, a reburn means at least a delay in restocking if not a completely barren area.

SEED TREE MORTALITY

If seed trees, scattered singly over cut-over land, are to be left by the logging operation as a source of seed, it is most important to know how they survive the exposure before it is possible to decide how many are necessary to attain regeneration and where they should be left.

It is a matter of common observation that the mortality of isolated old-growth Douglas-firs is high, whether they be defective trees automatically passed up in logging, seed trees purposely left as such, or individual trees that escaped destruction in a forest fire.

To get specific information on the life of isolated seed trees, the history of hundreds of seed trees left purposely on 11 typical logging operations on the national forests (Figure 1), widely distributed up and down the Cascade Range, has been recorded.[25] These were all in the Douglas-fir type, not in the spruce-hemlock or hemlock-balsam firs types, and the study was confined to Douglas-fir trees (Plate 15). Sitka spruce, hemlock, cedar, and the balsam firs are notoriously shallow-rooted and subject to windfall losses and are also so thin-barked that they are highly subject to logging and slash-fire injuries. Three of the 11 study areas were destroyed by accidental fires, and the historical record for them abandoned. Six of the 8 remaining areas were slash burned and the other 2 were not. Table 17 shows that the average mortality of seed trees during the 11- to 15-year period for the burned areas was 90.7 per cent and for the unburned plots 35.0. The losses were extremely variable; the heaviest sustained was 98 per cent, and the lightest 8; the averages and the difference between the losses on the burned and unburned should be taken only as indicative, since the samples are too few to give a true average, considering the large number of variables. More than half of the loss occurred during the first 5 years.

TABLE 17.—SUMMARY OF DOUGLAS-FIR SEED TREE SURVIVAL STUDIES

Name of area	Remarks: Seed trees	Remarks: Slash	Number trees at start	Years observed	Per cent dead at end of period
Williamette No. 1[1]	Single	Not burned	49	15	73.5
Williamette No. 2	Single	Not burned	71	15	8.4
Santiam	Single	Burned	49	15	91.9
Mt. Baker No. 1	Single	Burned	30	14	76.6
Mt. Baker No. 2	Single	Burned	50	14	98.0
Mt. Baker No. 3	Single	Burned	100	13	97.0
Mt. Hood No. 1	Single	Burned	98	13	90.8
Mt. Hood No. 2	Grouped	Burned	92	11	83.7
Totals and averages					
Unburned			120	....	35.0
Burned			419	....	90.7
Both			539	....	78.3

[1]Plate 15.

[25]Isaac, L. A. Mortality of Douglas-fir seed trees on cut-over lands. Pac. N. W. For. Expt. Sta. Forest Research Notes No. 31:11-12. 1941. (Mimeographed.)

PLATE 15.—Typical Douglas-fir seed trees 1 year after logging on unburned plot with timber edge in the background (Willamette No. 1, Table 17). Fifteen years after logging 74 per cent of these trees were dead or windfallen.

On one area the trees were left in blocks of 30 to 60 trees, but special care was not taken to leave them where they would be most free from fire and windfall loss, and as a result there was a mortality of 84 per cent.

There are 5 principal causes for this high mortality, all quite obvious: (1) Wind takes a high toll, particularly the first year after logging; in addition to trees that are uprooted, some are broken off and others are root-sprung and eventually die. (2) Logging breaks the tops out of some trees, knocks them over, or so scars them that they die; the fires from

slash burning often aggravate the scarring so that together these agencies are fatal, when either alone would not be. (3) Slash burning kills some trees instantly by actually scorching the crowns, others by burning out holes in the trunk so that they break off, and others by super-heating the trunk (and perhaps roots) so that they ultimately succumb; subsequent fires supplement the destruction of the initial slash burn. (4) Bark-beetle population builds up, for the first year or slightly longer, in Douglas-fir slash- and fire-killed timber, and, as this material dries out, the insects sometimes attack and kill remaining isolated live trees. This bark-beetle activity has been very destructive in killing "islands" of green trees and single trees in the great Tillamook burn that survived the fire itself (*8*). (5) Exposure to the elements is a general term used to explain the death of isolated trees several years after the logging and slash burning, which cannot be attributed directly to wind, fire, or insects, and may be due to the after-effects of a combination of these agencies or to physiological upsets caused by their sudden change from the sheltered to the exposed environment.

On the test areas over half the loss on the unburned tracts and a little over a third on the burned tracts was due directly to wind. Logging and slash burning account for over a quarter of the losses, not including the after-effects of burning, which are hard to distinguish from insect- and exposure-killing. In spite of all these adverse factors many Douglas-firs thrive, expand their crowns, and produce seed for many years after being isolated.

Seed-bearing trees, that stand singly or in small groups in cut-over slash-burned areas or that survive as remnants of a virgin forest that has been swept by a crown fire, sometimes die from 1 to 10 years after the slash or crown fire occurred from the after-effects of the scorching or from bark-beetle attack. During this interval they may produce considerable seed, which results in regeneration. When such areas are examined after the seed trees are dead, it is not easy to account for the reproduction that postdates the burning, and in the past it has at times been mistakenly attributed to seed stored in the duff for several years or to seed blown in from a distant seed source. This condition was noted by the author on the seed tree survival study and on the repeatedly examined plots in cut-over lands, as well as on the great Tillamook burn of 1933.[26]

Trees on ridge tops and dry, exposed slopes are quite wind-firm in comparison to those just over the lee side of a ridge or on moist sites. Trees left on the lower part of steep slopes and V-shaped canyons are highly subject to both fire and logging damage. Seed-tree mortality will be less if areas of low hazard are left unburned. A great deal can be accomplished toward reducing losses by carefully selecting trees that are so located and of such a type as to be least subject to injury from logging, fire, or wind. This study gives warning that under the conventional high-lead steam logging, usually followed by broadcast burning, a loss of half or three-quarters of the seed trees may be expected in a decade—with losses varying greatly in different localities—but may be materially lowered by better technique in picking the reserved trees, in logging, and in slash disposal. Plate 16 illustrates seed trees left singly and in groups under a wide range of conditions.

[26]See footnote 10.

PLATE 16.—A typical Douglas-fir cut-over area where a seed supply is provided by leaving mostly cull or unmerchantable trees in several forms. A study of the picture will show single seed trees, seed trees in small groups, patches of immature or otherwise unmerchantable timber, strips of timber between machine settings (long corners), and strips of timber along stream courses and ridge tops. If fires are kept out, this area will in all probability restock promptly.

AMOUNT OF SEED REQUIRED FOR ADEQUATE REGENERATION

The foregoing discussion of seed production, dissemination, and survival and of the many factors favorable and unfavorable to germination and seedling establishment leads up to the very practical questions—how much seed of Douglas-fir is required for adequate natural regeneration and how will it be provided? It is necessary to set a minimum objective; medium stocking within 10 years after logging is suggested, i.e., 40 to 69 per cent of the 4 mil-acre quadrats must have at least one established seedling, and this inevitably results in several seedlings on most of the quadrats or, on the average, about 900 per acre. In calculating the amount of seed required to get this result, allowance must be made for some seed falling on unfavorable ground, for seed destruction, for failure to germinate, and for the high mortality of seedlings in their first years. Soil, exposure, weather, competing vegetation, rodent population, and slash disposal practice are exceedingly variable.

With a most unfavorable set of conditions, an almost limitless amount of seed may fail to result in restocking, as on a brushy, mouse-infested south slope in the drier part of the region. While on a favorable site hundreds of thousands of seedlings per acre have been known to result from a single seed crop. If the rodent population were negligible, seed-bed conditions favorable, the weather seasonable, the slash not burned, and the degree of shade just right, a pound of seed (40,000 seeds) to the acre should result in adequate regeneration in a short period, but this favorable combination of conditions practically never occurs in nature.

Toumey and Korstian (*34*) estimate that 6 to 12 pounds per acre are needed for broadcast seeding. The author has seeded experimental plots on severe sites at the rate of 10 pounds per acre applied at one time and not obtained a satisfactory stand. Seed traps on a typical slash-burned, cut-over area in the Wind River Valley showed a total seed fall of 8 pounds in 7 years. A stocked quadrat check of this area made in November 1940 showed that this 7 years of seed fall resulted in full stocking with well established seedlings. Obviously the amount of Douglas-fir seed provided for natural regeneration should be in relation to the local and immediate conditions. As a very broad average for prevailing ground conditions over the region, it is suggested that 8 pounds to the acre, naturally disseminated over a period of 6 or 8 years, should result in satisfactory restocking. This may be disseminated in 1 or more heavy and some lesser seed crops, but within the first few years after logging; otherwise, competing vegetation greatly lessens its effectiveness. If it takes 8 pounds of seed to produce 900 established seedlings, that is a ratio of about 355 seeds to each seedling.

SILVICULTURAL TREATMENT TO OBTAIN DOUGLAS-FIR REGENERATION

Assuming that a certain amount of seed (for average conditions, 8 pounds per acre) will result in satisfactory reforestation after logging, it is next necessary to answer the second question—how will that seed be provided? In addition to determining the number of seed trees required, it is necessary to be sure that the seed source is so located as to give sufficient dissemination over all parts of the area to be regenerated. Ordinarily a conscious effort must be made to so conduct the cutting that a properly spaced seed source will be provided by methods to be discussed later, but there are rare situations when seed trees are not needed or desirable. Two of these situations will be mentioned: First, where logging is done in the fall and winter following a good seed crop and the slashings will not be burned. Here it may be assumed that the ground will have been adequately seeded by the trees that are logged, and barring accidental fire no further seed source is necessary. Second, where there are only sound, valuable trees to leave as seeders, or where seed trees would not be likely to survive, it may be prudent policy to leave no seed sources and to plant the clear-cut area with nursery-grown trees. Artificial reforestation must also be relied upon to supplement natural seeding where the latter fails, is too long delayed, is accidentally burned, or is of undesired species.

There are three principal methods of providing seed in the course of logging Douglas-fir timber: (1) from single seed trees, (2) from timber on the sides, and (3) from the reserve stand in partial cutting. Each of these silvicultural treatments will be briefly discussed.

Single Seed Tree Method

Character of Seed Tree

This method presupposes leaving individual trees of seed-bearing size and of a type likely to survive, distributed more or less uniformly over the area (Plates 15 and 16). Sometimes they will be left in small clumps, but where a group of trees large enough to give mutual support against wind is left, it should be classed in the next category—seeding from the side. Since "conky" trees (those affected with ring scale fungus, *Fomes pini* and other rots) are prevalent in the region, particularly toward the south on the Cascade Range, it is a natural practice to leave such of them as are unmerchantable or of questionable merchantable value. This is done automatically on many operations even though there is no conscious thought of providing for reforestation, as well as on other lands where there is a purposeful intent to provide a seed supply.

The question has been raised whether or not the progeny from the seed of conky trees will exhibit any inherited weakness or tendency to decay that might make this practice undesirable. Boyce (*4*) says:

"... if decayed trees with conks are reserved for seed trees, they will do little if any harm, since under proper management the succeeding stand will in turn be cut before it has attained the age at which there can be appreciable loss through decay. Also, it is unlikely that decay of the dead heartwood will affect the vital functions of the tree so as to reduce the quality of the seed."

A limited amount of tests in the plantations of the progeny of conky trees and of sound trees (1 parent only) shows no differences between them in height growth after 17 seasons (*32*) or in diameter growth after 27 seasons.[27] Sound trees are sometimes left singly on national-forest logging operations, but this practice has the economic objection that the merchantable value of even 1 or 2 large sound trees per acre is greater than the cost of artificial planting, and most of them ordinarily will have no future salvage value, even if they survive the regenerating period.

Single seed trees should naturally be those with good full-foliaged crowns likely to bear cones, and of such a size and form and so situated that they have a good chance to survive logging, wind, and slash burning.

Number of Seed Trees

On national-forest timber-sale areas it was the practice for years to leave a minimum of 2 Douglas-fir trees per acre for reseeding purposes, usually conky or otherwise unmerchantable trees. Sometimes there were so many conky trees that many more than this were left. With only 2 per acre the results in a 10-year period have seldom been satisfactory, partly because such a large proportion of them died from fire, wind, or insects before they had done much seeding. With 8 or more seed trees left per acre restocking has usually been good in a similar period, barring accidents from fire.

If 8 pounds of seed per acre are necessary on the average, and the ordinary seed tree produces a pound of seed in a very good seed year, 4 average-sized trees ought to produce the requisite 8 pounds in 2 or 3 seed crops, that is within the first 6 or 8 years after logging, if the trees live. But since there are known heavy losses, it would be well to leave double this number as a factor of safety. The larger number is needed if trees are small and probability of loss is great and, conversely, less are needed if trees are large and the probability of loss is low. If the seed trees are carefully selected and safeguarded from fire, it is not likely that their mortality will be as great as past seed-tree survival records indicate.

In some localities in addition to the big Douglas-fir trees that are left purposely for seed, or because they are unmerchantable, there are left standing understory or unmarketable hemlocks, cedars, and balsam firs. When not killed by slash burning, these trees will cast some seed and supplement the Douglas-fir regeneration.

The high shade cast by 6 to 10 seed trees per acre, unless they were unusually large, would be beneficial to seedling establishment. Enough of them will probably die over a period of years so that they are not likely to retard growth of the new stand.

Too many seed trees may bring about a serious condition. The larger

[27]Munger, Thornton T. and Morris, W. G. Further data on the growth of Douglas-fir trees of known seed source. Pac. N. W. For. Expt. Sta. 12 pp. 1942. (Mimeographed.)

the number the less likelihood there is of loss from fire, windfall, or insects. Since conky trees may live on indefinitely, if too numerous they may retain possession of the site and utilize most of the growing space. Furthermore, hemlock, cedar, and balsam firs may occur in mixture with Douglas-fir anywhere in the region; they reproduce readily, yet produce a satisfactory tree or stand in only about a third of the region. These trees (except noble fir) are tolerant, much more so than Douglas-fir, and although a light shade is admittedly beneficial to Douglas-fir seedling establishment, an undue increase in shade will reduce the chances of establishment and better the opportunity for tolerant species to become established. Therefore, an abnormal number of defective trees should not be left where the object is Douglas-fir regeneration, even though they are worthless.

The seed-tree losses after logging and the detrimental effect of too many seed trees on the growth and development of regeneration are substantiated by observations on cut-over lands throughout the region.

The records show that seed-tree losses are likely to be somewhat concentrated or patchwise; complete dependence on seed trees, therefore, either singly or in small groups, to reseed cut-over land is fraught with uncertainty. On every large area some provision should be made for a supplemental seed source from the side or for planting in spots where seed trees are lost through accidental fire, windfall, insects, or other causes.

As a guiding principle, it should be recognized that seeding distance is such that trees on every acre are not necessary and wide gaps are permissible if the seed supply is large. Therefore, scattered defective trees, if sufficiently numerous, may be selected in concentrated groups where they would be least subject to loss from logging, fire, or windfall. There is certain to be some loss of single seed trees over a 10-year period, even if extreme care is exercised in selecting them. Considering amount of seed required, seed productivity, and seed tree losses over a 10-year period, it is calculated that it will be necessary to leave an average of 8 seed trees per acre; and since it has been shown that a larger number may retard restocking, an average of 8 trees per acre is set up as the desirable number to leave for seeding purposes. If the stand does not contain a sufficient number of unmerchantable or low-value trees in suitable locations, then they should be supplemented by a seeding source from the sides, as discussed below, or regeneration attained in part at least by artificial planting.

Douglas-fir seed trees, left singly or in groups in sufficient numbers, while not a positive assurance of complete natural regeneration, will restock most cut-over areas in a 10-year period. Since conky trees occur in sufficient numbers in many stands, and can be left at no cost or often at a saving to the owner or logger, they constitute a most important seed source for natural regeneration.

Slash Disposal with the Single Seed Tree Method

As indicated in preceding pages, slash burning is, in most cases, not advantageous for Douglas-fir regeneration. It may lessen the chances for quick and adequate natural reforestation by burning up the seed on the ground, impairing the surface soil conditions, and killing all the advance reproduction and some of the seed trees. It has, however, some very im-

portant and often preponderant advantages, namely, quick removal of some of the fire hazard, thus facilitating subsequent fire control and lessening the chance of disaster from an uncontrollable fire; also, burning often removes excessive debris and vegetative cover and exposes the mineral soil to easy access by the germinating seed. The logging operation alone sometimes does not bare a sufficient amount of the surface to assure regeneration, even if there is an adequate seed source.

Where the exigencies of fire prevention or cover dictate slash burning, it should be done; where they do not, existing regulations provide for making application to the State Forester for a release from the legal requirements for slash disposal.

The following principles are suggested by Munger and Matthews (*31*) for the guidance of those confronted by the question—whether or not to burn:

Slashings should be burned:

1. Where the chances of accidental fires are high or the opportunities for fire control are poor.
2. Where the cutting is clean and there is not an understory that would be killed by the fire and make another hazard comparable to the initial slash.
3. Where the conflagration hazard is high, due to very extensive areas of recent cuttings.

Do not burn slashings:

1. Where a considerable reserve stand or understory would be killed by fire, thus making little or no net gain in reducing the fire hazard.
2. Where the logged-off area is well isolated from risk of fire and is not a particularly high hazard in itself.
3. Where a good stand of advance or subsequent reproduction promises to give shade and reduce fuel inflammability in a very few years.

The author would add a fourth point to each of the three recommendations given above; they are (1) burn whenever debris and ground cover are so dense as to prevent seedling establishment, (2) do not burn if there is an abundance of seed on the ground from the current year's crop, or if a good stocking of seedlings have germinated since cutting.

Techniques to be followed in burning are given in detail by Munger and Matthews (*31*). Where single trees are left for seeding purposes, precaution should be taken in setting the fires to spare the trees as much as possible from having the flames sweep into their crowns or from intensely hot fires burning around their bases.

Seeding from the Side

Character of Seed Blocks

Where there are insufficient unmerchantable trees for a seed source, rather than leave single merchantable trees it is preferable to leave patches, blocks, or strips of timber within seeding distance on all parts of the clear-cut area. These may be in the form of strips along creeks, highways, or ridges, "long corners," or in large blocks—such as where the settings are staggered (Plates 16 and 17). The seed source is not as adequate nor

PLATE 17.—The "staggered setting" or block system of clear cutting where blocks of timber are left to furnish a seed supply and aid in fire protection. These blocks may consist of young growth or otherwise unmerchantable timber or of timber to be logged at a later date when surrounding cut-over land is reseeded. The fan-shaped patterns mark the high-lead skidder setting, and the irregular network of trails in the right center shows the pattern of a setting logged by tractors. Light colors show portions of the area that are being left unburned.

as ideally located in Plate 17 as it is in Plate 16; nevertheless no part of the area is more than a quarter-mile from a seed source. Various methods of attaining this end are illustrated in the "Handbook of Forest Practice for the Douglas Fir Region" (*36*). Where blocks of considerable size are left, it would be the expectation to log them after the intervening areas have been reforested. Often seeding from the side can be attained, without the sacrifice of marketable blocks or strips of timber, merely from adjoining bodies of submerchantable, yet seed-bearing, timber. In most extensive old-growth stands of this region, intermingled with the commercially valuable timber are patches of immature forest, side hills of young hemlock with scattered old-growth Douglas-fir, or upper slopes of inaccessible or inferior timber which can well be left by the logger and which will go a long way in furnishing a seed supply.

Spacing of Seed Blocks

Distance from seed source is the important consideration in the selection of these reserved blocks and strips. It should be remembered that adequate regeneration under average favorable conditions cannot be attained in a reasonable time for a greater distance than a quarter of a mile from the edge of a body of seed-bearing timber. Hence, there should be left sufficient patches, strips, and blocks of timber so that no part of the cutting will be more than about a quarter of a mile from a seed source, and on the average at least 8 pounds of seed per acre will be scattered in the course of 2 or 3 good seed crops. If site conditions are unfavorable for seedling survival the seeding distance should be proportionally less than a quarter-mile. Since seed trees in blocks are relatively less effective than single trees, there should be left proportionally more for each acre of cut-over land than under the single seed tree method. These are theoretical calculations of seed-block requirements, and are suggested merely as guides. The actual distance between seed sources and the size of seed blocks must be varied to fit the lay of the land and the variations in the original forest. The evidence indicates that a solid bank of timber, that will stand for a 10-year period, can be counted upon to seed up in that time the adjoining area for a quarter of a mile from the timber's edge, where the topography and edaphic conditions are favorable. This method is likely to result in a varied distribution of the regeneration—dense stocking close to the seed blocks and proportionally lighter stocking as the distance from them increases.

Attention has been directed principally to the measures necessary to get at least a minimum number of seedlings for satisfactory stocking on all parts of the cut areas. It is obvious that with an especially favorable combination of conditions, far more than this minimum requirement may be obtained, especially close to seed blocks. Should there be a maximum limit to the seed sources? It is true that at times Douglas-fir reproduces far more prolifically than is necessary, and thickets of great density develop. However, stands of this species do not tend to stagnate in the seedling and sapling stages from competition with their own kind, as do young stands of hemlock and cedar. The more forward individuals assert dominance, keep their tops in the light, grow faster, and soon suppress their competitors. A very considerable factor of safety is necessary to always

achieve the minimum. It is, therefore, not thought very necessary, or at all practical, to limit the maximum of the seed source to forestall overcrowding either with the single seed tree method or with seeding from the side, except to avoid too much shading of the ground as discussed in a preceding chapter.

Often in actual practice, seeding from the side will be combined with the single seed tree method, or with artificial planting and better distribution of regeneration attained thereby.

Slash Disposal with the Seed Block Method

As with the single seed tree method of clear cutting, broadcast slash burning is the prevailing practice, and the same guiding principles quoted above apply where seeding from the side is desired. With the latter method, there is less danger of destroying the seed source than with the single tree method. Care must be taken, however, to set the fires so they will burn away from, not toward, the seed blocks. It is often difficult to prevent killing the timber along the edge on the uphill side.

Partial Cutting Method

Since the introduction of tractors in Douglas-fir logging, there has been an increasing amount of partial cutting, or "selective cutting."[28] It varies in form and intensity from cuts of less than 25 per cent of the stand carefully selected for cutting as on some national-forest timber sales to very heavy cuts, so-called "zero-margin cutting" or "high grading," taking all marketable trees without conscious thought for the residual stand. Partial cutting sometimes takes the form of area selection or group selection, where the reseeding actually comes from the side rather than from overshadowing trees; this has been called "clear cutting in miniature" (*29*) and for the purposes of this discussion of regeneration comes in that category.

The application of partial cutting to the Douglas-fir region involves two rather distinct though merging problems: (1) Converting virgin stands of Douglas-fir and tolerant species into desirable residual stands, and (2) harvesting even-aged, younger Douglas-fir stands, in each instance striving to obtain natural regeneration of the species most desirable for the site.

Seed Supply Not More Important Than Controlling Degree of Shade

There is an abundant seed supply when partial cutting is practiced, more than enough to achieve natural regeneration, but the problem lies in securing enough Douglas-fir seed and not too much of its more tolerant associates. But even with an adequate seed supply in the Douglas-fir region the composition of this reproduction may be to a large extent dictated by the type of partial cutting practiced. It is important, therefore, to take account of the regenerative characteristics of Douglas-fir in relation to those of its associates, especially the intolerance of Douglas-fir seedlings of shade.

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[28]The term "selective cutting" is discussed in the Introduction.

Given moderate, more than half, overhead light and growing space, Douglas-fir soon dominates its more tolerant competitors—hemlock, cedar, and the balsam firs. But a further reduction of either overhead light or growing space or both favors the competitors and retards Douglas-fir to its ultimate elimination from the regeneration.

Established reproduction of tolerant species is present in most natural stands in the region, and this reproduction responds to even the slightest opening up of the forest by partial cutting or by natural causes. That is why these tolerant species take possession of a site as Douglas-firs mature and fall out one by one in the natural life cycle of the stand. Douglas-fir, on the other hand, must wait until opening up is sufficient not only to permit seedlings to become established but also to compete with the established seedlings and saplings of tolerant species that thrive in the shade. Under natural conditions on logged-off lands, Douglas-fir reproduction is not becoming established after cutting unless half or more of the crown has been removed and unless there are not too many established tolerant competitors present. At times selection of veteran Douglas-firs from a mixed forest and leaving only hemlock, cedar, and balsam firs results in elimination of the Douglas-fir from the stand because of the lack of seed, even though light conditions might admit some Douglas-fir.

From detailed experiments and from general observations of existing conditions in the field, it is evident that Douglas-fir natural reproduction cannot be obtained under light, individual tree selection cutting. If Douglas-fir regeneration is desired, the removal will have to be heavy, and heavy cutting invites wind throw in this type. Therefore, if partial cutting is practiced, with Douglas-fir regeneration in view, the early cuts should necessarily consist of light improvement cuttings, and the final cut should be heavy enough or patchwise enough to permit Douglas-fir seedling establishment—and in either case some salvage cutting should be anticipated because of the probability of windfall. If the selection is patchwise the opening will have to be an acre or larger in size, and this, as stated above, is in effect clear cutting in miniature.

Slash Disposal with the Partial Cutting System

If the partial cutting takes a light cut (for example less than 25 per cent of the stand) it may not create a slash hazard that requires abating, but if more of the stand is taken, a hazard is created which is dangerous and which is extremely difficult to abate without great expense or without doing damage to the reserve stand. The removal of the slash is not necessary to secure regeneration, but it is a fire threat to both the reserve stand and the reproduction. This hazard increases at a faster rate than the increase in per cent of cut and lasts until the slash has been burned or rotted down. Broadcast burning is fatal to the thin-barked trees, may result in a holocaust, and may leave in its wake a forest of dead snags that are as bad a menace as the slash. Experiments in controlled burning with some hand-piling of slash have been successful but expensive. Spot burning has at

times been effective in getting rid of some of the slash without too much damage to the residual stand, but days when this can be done successfully are rare. Intensive protection is sometimes used as a supplement to or substitute for other hazard reduction measures.

It appears that following cutting in mixed stands, the greater the amount of burning the more will Douglas-fir be favored over its competitors, and if more Douglas-fir is wanted this is a desirable objective. But burning may do more harm than good, as pointed out above, and is at best a hazardous and difficult way of controlling the mixture of species after partial cutting. It should be remembered that in practicing partial cutting in old mixed stands, the composition of the future forest will be controlled more by the advance young growth of seedlings, saplings, and poles than by the reproduction starting subsequent to logging—except where there is a general surface burning or a great deal of soil disturbance by logging.

SUMMARY

In the important Douglas-fir region of western Washington and western Oregon, a large proportion of the lands cut over in the last two decades have failed to restock satisfactorily with tree reproduction. This is due partly to uncontrolled fire and partly to other factors which this circular discusses.

Douglas-fir produces seed abundantly with complete seed crop failures only every fourth or fifth year. Mature trees produce about a pound of seed on a good seed year, much of which falls within the radius of the tree's height. Much seed is destroyed by rodents, birds, and slash burning, and much does not land in a suitable seed bed. Few seeds retain their viability on the forest floor more than a year.

Seedling establishment is governed by a number of factors. A maximum surface soil temperature of 125° F. is fatal to very young seedlings. Spring frosts, summer droughts, winter frost heaving, disease, insects, and animal predators all take their toll, so that a very small percentage of germinated seed results in established seedlings. Shade, particularly "dead shade," protects the seedling from some of these unfavorable factors, but young Douglas-fir at no stage can endure full overhead shade, such as cast by a virgin forest or very dense ground cover.

There is great variety in the climate and soil of the region which is reflected in the restocking of logged-off lands. From north to south there is a progressive decrease in precipitation and increase in intensity of insolation along the Cascades, both of which make reforestation more uncertain. Fire has an important effect on the surface soil, particularly in making its physical, moisture-holding capacity less favorable to seedling establishment.

Herbaceous and shrubby vegetation is commonly prolific and rank on cut-over land. The shrubs offer more serious competition than the herbs. When the density of the cover is more than "moderate," 60 to 75 per cent, Douglas-fir seedlings are confined chiefly to the more open spots. A controlled study of shade indicates that Douglas-fir reproduction has little or no chance of successful establishment in anything less than 20 per cent of full overhead light, even where there is no root competition. Under timber cover, it will probably not thrive in less than 50 per cent of full overhead light.

The grazing of livestock for a period of 5 to 10 years on cut-over land not seeded to grasses is considered an acceptable practice of forest management which will be harmless to the tree regeneration, provided the grazing is light and carefully administered.

Douglas-fir seedlings grow very little the first three or four years, and even the dominant seedlings do not reach a height of 5 feet until about 9 years of age on the average site; their ability to overtop the competing vegetation is a factor in determining their survival. Seedlings in a light weed cover were found to grow twice as fast as those in a heavy brush cover.

Observations of a number of representative cut-over areas through a term of years provide some interesting case histories. On comparable clean-cut areas in the Wind River Valley, one a favorable northeast exposure and the other a hot southwest slope, the former was fully stocked in 10 years for a quarter of a mile and in 22 years for a half a mile from the timber's edge, while the latter was well stocked for only about 100 feet from the seed source after 22 years. Other areas showed a similar inverse ratio between number of seedlings and distance from seed source, as well as the pronounced effects of exposure and of surface burning. Unburned cut-over areas in general show more Douglas-fir regeneration than burned areas; but occasionally burned areas restock as quickly as unburned. Reburning further delays restocking and often results in barren areas because it not only destroys all established seedlings and some remaining seed trees but occurs at a time when many of the original seed trees have died and the cutting edge of the standing timber has moved beyond seeding distance.

The mortality rate of single seed trees left after logging is variable and high, especially where the slash is burned. Observations of some 539 trees on 10 areas show that 78 per cent were down or dead 11 to 15 years after logging. Less burning and more care in locating trees will reduce losses.

To obtain by natural regeneration medium stocking in 6 to 10 years after logging, it is thought that on the average 8 pounds of seed to the acre are necessary; it will be less where conditions are favorable, more where the site is severe and predators are active. Natural reseeding may be achieved after clear cutting by leaving single seed trees, by leaving strips or blocks of timber which will reseed cut-overs from the side, or, more rarely, from an abundant crop of seed already on the trees to be felled the following fall and winter. Single seed trees are advised particularly where there are in the stand submerchantable trees that are suitable as seeders. If an average of 8 trees per acre is left, it is probable that 4 or more will survive for a period of 6 to 10 years, which should be adequate for reseeding. More than 8 large trees is likely to be unfavorable to the young growth. Where the exigencies of fire prevention or excessively heavy cover or debris dictate, slash burning should be done; otherwise not.

Seeding from the side may be achieved by leaving strips along creeks, highways, or ridges, "long corners," or large blocks, so spaced that no part of the cutting area will be farther than a quarter of a mile from an ample seed source. There should be enough potential seed production in these blocks to provide an average of 8 pounds of seed per acre during the first 6 to 8 years after logging, and it must be remembered that from large blocks most of the effective seeding is done by outer fringe trees only. As with the single seed tree method, where slash burning is necessary, broadcast burning is recommended and the same guiding principles of when to burn and not to burn apply.

Where partial cutting, rather than clear cutting, is employed there is an abundant seed supply when all species are considered, but the problem lies in securing an adequate proportion of seed of the desired species; in one instance it may be Douglas-fir, in another it may be one or more of the tolerant species. Given an adequate seed supply the amount of overhead shade will largely govern the composition of the regeneration. With more

than half overhead light and growing space or with complete openings of an acre or more, Douglas-fir should dominate its more tolerant competitors, but less than this is likely to result in elimination of Douglas-fir in favor of hemlock, cedar, and the balsam firs, in most parts of the region.

In certain old forests, where partial cutting might be practiced, reproduction of tolerant species is already present, and is apt to persist to the exclusion of subsequent Douglas-fir reproduction.

Burning tends to favor Douglas-fir regeneration in competition with hemlock, cedar, spruce and the balsam firs, particularly after partial cutting. Controlled spot burning or partial piling and burning at times is practicable and effective. But slash disposal in general is extremely difficult following partial cutting and may do more harm than good to the reserve stand.

Conditions within the Douglas-fir type are so varied that simple, specific rules cannot be set forth for securing regeneration over large areas, either in the management of young stands or the harvesting of over-mature virgin forests. However, careful study of all local factors coupled with an earnest application of the findings set forth in this publication will produce far more satisfactory regeneration than has been obtained in the Douglas-fir region in the past.

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